On-site Wastewater Treatment and Reuse Using Recirculatory Evapotranspiration Channels in Regional Queensland

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Abstract

The Central Queensland University developed an on-site wastewater treatment and reuse technology. Septic tanks were used for primary treatment and the discharged effluent was then pumped though a series of contained channels. The channels were designed to be a modified evapotranspiration trench; they were comprised of an aggregate layer and a soil layer in which were planted a variety of plants. The aggregate and the soil provided physical filtration, the microorganisms within the effluent, aggregate and soil provided nutrient reuse and transformation and the plants also used the nutrients and reused the treated effluent through evapotranspiration. Any effluent that was not transpired was returned to a holding tank and pumped through the evapotranspiration again. The treatment technology was assessed in relation to its ability to treat effluent in a sustainable manner. The water and soil was examined for concentrations of nutrients, heavy metals, salts, sodium, and organic carbon %. The pH, temperature and number of colony forming units of certain microorganism potential pathogens were also inspected in the soil and the water. The plants grown within the evapotranspiration channels were assessed in regards to their health, water usage, and in some cases potential pathogens on fruit. The infrastructure that was used to construct the wastewater treatment and reuse system was also evaluated in regards to reliability and maintenance. Certain limiting factors, in particular sodicity and salinity were identified, but the trial was successful and a sustainable form of on-site wastewater treatment and reuse technology was developed.

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Acronym List

AS: Australian standard

AS/NZS: Australian and New Zealand standard

AWTS: Aerated wastewater treatment system

CEK: *Citrobacter*, *Enterobacter*, and *Klebsiella*

CFU: Colony forming units

CQU: Central Queensland University

DWV: Drainage, waste and vent

NFH: Non-fastidious heterotrophic organisms

PSG: Plant Sciences Group

PVC: Polyvinyl chloride

RET: Recirculating evapotranspiration channel

UV: Ultra-violet

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Declaration

I declare that the main text of this thesis is an original work. I have published some of the material contained within this document in conference and journal papers. I have not submitted any of the material in this document previously for a post-graduate degree.

Signed

Benjamin Mark Kele

Chapter 1: Literature Review

1.1 Literature Review

This review will examine the published literature on on-site wastewater treatment technologies and the associated potential risks. The focus will centre on Australian conditions, although some international perspectives will be discussed.

1.1.1 Water Efficiency

Clean water is a limited resource that has in recent years become more scarce (Fullerton 2001). Arguably the most important issue in wastewater treatment and effluent reuse is water efficiency. Huge volumes of wastewater are needlessly produced because water use is inefficient – outdated infrastructure and practices inflate the volume of wastewater requiring treatment. Such wasting of water puts pressure on strained fresh water catchments and on the wastewater treatment plants that have to handle the excess. Approximately 70% of Australia's fresh water is used for agriculture (ANZECC and ARMCANZ 1999). Irrigation of crops and pastures through inefficient techniques, such as flood and overhead sprinkler, requires very large volumes of water (ANZECC and ARMCANZ 1999). Sub-surface irrigation uses a much smaller volume of water but has greater infrastructure costs (ANZECC and ARMCANZ 1999; Oron *et al.* 1991; Stewart and Salmon 1986; Zhang *et al.* 1998). The relatively high-cost of water efficient irrigation techniques has traditionally prevented many farmers from using them.

In recent years the rising cost of water and the scarcity of supply is making water efficient irrigation an economically practicable option (Fullerton 2001). Domestic dwellings and urban commercial operations use about 20% of Australia's clean water supplies (ANZECC and ARMCANZ 1999). Water efficient infrastructure, such as reduced flow showerheads and dual flush toilets, in households dwellings are a feasible economic alternative to more wasteful traditional installations (Langford 2003). Most types of water-efficient infrastructure are passive in nature requiring no specialised knowledge for people to use them. Through the provision of rebates for retrofits of existing non-water efficient components and the mandating in legislation that new buildings and developments use water-efficient infrastructure the growth in water demand can be reduced (Anderson 2003; Hatton-MacDonald 2003; Langford 2003). In the urban environment water efficiency is at the present time more cost-effective than most types of effluent reuse (Anderson 2003). It is important to acknowledge in wastewater treatment and reuse studies that the first step is to reduce the volume of wastewater produced.

1.1.2 On-site Wastewater Treatment

On-site wastewater treatment is where the wastewater produced by a facility is treated by a selected technology close to the location where the wastewater was produced (CET 2001; Geary 1993; Zeeman *et al.* 2000). On-site wastewater in Australia is used most frequently in areas where it is uneconomic to install a reticulated sewer line connected to a large-scale sewerage treatment plant (Booker 2000; Goonetilleke *et al.* 1999). There is some interest in on-site wastewater treatment and reuse in areas serviced by reticulated sewerage but so far the acceptance level of this is low due to economic and legislative restrictions (Bruce 2002; Kuai *et al.* 1999; Zeeman *et al*. 2000). There are a variety of on-site wastewater treatment technologies available that range in technological complexity (Geary 1993; Goonetilleke *et al.* 1999; Tchobanoglous 1996). These are reviewed in the following sections.

1.1.3 Pit Toilets

The simplest form of technology is the pit toilet. Pit toilets occur in variety of forms, from 300 mm ‘cat’ depth to an 8 m deep bore-hall pit latrine (Franceys *et al.* 1992). Pit toilets are most commonly used by a single household or in low use frequency areas (Franceys *et al*. 1992; Jelliffe 2001). They are common in developing countries as they have low cost, can be built by the householder, operate without additional water, passive in nature, and are easily understood by the community (Franceys *et al*. 1992; Jelliffe 2001).

The disadvantages include the potential for groundwater pollution, unsuitability for areas with more permeable soils, fly and mosquito problems, odour, a relatively short life, difficult to clean out, and if the pit is shallower than 1 m there is the potential for the spread of hookworm larvae (Franceys *et al*. 1992; Jelliffe 2001). While often ignored in the scientific literature reports on Australian on-site options, pit toilets are still commonly used in rural areas and in certain areas in National Parks, such as along low-usage walking trails (Jelliffe 2001). Many Australians have experience in using pit toilets and while during the 20th Century the amount of 'outback dunnies' in Australia decreased their use has not been eliminated.

1.1.4 Composting Toilets

Composting toilets are becoming increasing popular around the world (Franceys *et al*. 1992). The technology is frequently used to solve sanitation problems in rural and regional areas of developing countries, and they are promoted as an environmentally friendly and sustainable treatment option in more advanced nations (Davison and Walker 2003; Franceys *et al.* 1992; West 2001).

Compost toilets operate in a manner similar to pit-drop toilets with respect to the absence of a flush mechanism. In a composting toilet the faecal matter enters a large tank or container, to which is regularly added an additional carbon source, for example mulched paper, ash or chip bark, and organic matter such as vegetable scraps (Franceys *et al*. 1992). If the moisture content is controlled the faecal matter will compost. The tank is normally designed so that aged compost material can be removed from the bottom of the tank/chamber and used as a soil amendment (Franceys *et al*. 1992).

A variety of mechanisms can be used to remove excess liquid from the chamber. It is not unusual for worms to be added to the compost chamber creating an additional vermiculture treatment component. The worms used in vermiculture help reduce the thermotolerant coliforms, and the solids and the moisture content of the faecal matter, while accelerating the compost process (Kristiana *et al.* 2004). Vermiculture can be used in a variety of different on-site wastewater treatment technologies (Gunn 2003; Kristiana et al. 2004). The length of time that the faecal matter takes to fully compost depends on the design of the toilet. The most common designs used in Australia are the Minimus continuous flow (~ 2000 L capacity); Farallones batch device (~ 2000 L capacity), and the Barrel batch device (~ 200 L capacity) (Davison and Walker 2003). Those systems with a relatively small volume, such as a barrel batch device based on a wheelie bin, have a short compost time of approximately four months, whereas the larger devices, especially the batch models, may allow the faecal matter to compost over a three to five year period (Broukaert *et al.* 2004; Davison and Walker 2003; West 2001).

Davison and Walker (2003) reported that up to 70% of New South Wales compost toilets are constructed *in-situ* by the homeowner. Safton (1993) supported this conclusion in a Master’s thesis that closely examined six composting toilets, four owner-built, that also involved a broader review of composting toilets in Australia. Whether commercially bought or owner-built all composting toilets in Australia must produce compost to the performance guidelines of the AS/NZS 1546.2:2001 standard shown in Table 1.1.

Table 1.1 AS/NZS 1546.2:2001 Composted End Product Requirement

Characteristic	Performance Criterion
Consistency	All six samples shall contain no recognizable faecal material
Odour	No offensive odours permitted from the end product, effective immediately after removal
Moisture Content at removal zone pile base	Not to exceed 75% by weight (all six samples)
Thermotolerant coliforms	<200 colony forming units per gram dry weight (all six samples)
Salmonella spp.	Not detectable (all six samples)

Adapted from AS/NZS (2001) and Davison and Walker (2003).

Composting toilets are frequently used in developing countries or in remote areas in more developed countries (Franceys *et al*. 1992). Maher and Lustig (2001) worked on an AusAID funded compost toilet project on the Pacific Island of Kiritimati. Compost toilets were considered the most appropriate technology for the island, as the soils were poor, electrical power was limited, and the area had low rainfall but high water tables. A previous compost toilet program on the island had failed due to a lack of maintenance and community education and acceptance (Maher and Lustig 2001). The original design of composting toilet on the island was a relatively tall structure and allowed the community to view very easily who was using the facility. The culture of the island has a very strong faeces taboo and a belief that black magic can be worked against a person if someone who wishes ill-will obtains a faeces sample. Maher and Lustig (2001) redesigned the composting toilet to a low double vault structure that reduced the visibility of the building in the community and embarked on a wide scale community education and maintenance-training program. They found that this approach was highly successful and were able to recommend that composting toilets were a suitable on-site technology for coral atolls. One of the largest composting toilet programs currently being researched is in South Africa and was discussed in Broukaert *et al.* (2004). This program deals with rural and regional South African townships that have previously had very poor standards of sanitation. Double vault batch composting toilets with sub-surface drainage fields for the excess liquids have been installed in large numbers. Each toilet is expected to serve a cluster of houses (Broukaert *et al*. 2004). Several months prior to installation a community education program is undertaken. The education program teaches why the sanitation is important as well as the operation and maintenance of the composting toilets (Broukaert *et al.* 2004). Large numbers of the composting toilets have been in operation in numerous South African communities for over three years and the types of community problems encountered by Maher and Lustig (2001) have not occurred to the same extent.

Composting toilets are not restricted to developing countries or to owner-built facilities in places such as Australia. West (2001) reports that in Scandinavia a blackwater wet composting system has been developed and marketed internationally as the Aquatron^{tm}. The system requires no electricity and has no mechanical moving parts; but would be difficult to entirely manufacture *in-situ* in developing countries as it is constructed in a plastic injection mold (West 2001). Liquid run-off from the treatment chamber is disinfected by ultra-violet light, stored in a separate tank and under normal operating conditions reused for garden irrigation (West 2001). A vermiculture system is established in the wet compost and is expected to reduce the volume of solids by 90%. The wet composting area is designed to hold up to five years worth of solids. The solids are typically used as soil amendments in fodder crop production. The laws of the EU prevent the solids being used to fertilise crops used directly for human consumption (West 2001). The technology is temperature dependent and works most effectively at temperatures of 12^{o}C - 25^{o}C. West (2001) indicated that the biggest limitation of the technology is its inability to treat greywater. Jelliffe (2001) in a comprehensive review of viable on-site wastewater treatment options for Australian National Parks describes composting toilets as an important technology. National parks are frequently limited in their access to electricity and water. The advantages that Jelliffe (2001) describes include the ability of composting toilets to operate without a water and electrical supply, and the relatively low volume of wastewater discharged. The limitations of composting toilets listed include; susceptibility to daily changes in the loading, relatively high maintenance level with regular additions of carbon and other organic matter required, tendency to become waste holding systems when overloaded and the composting process is impeded, and regular need to remove composted materials.

1.1.5 Septic Tanks

The septic tank is the first technology described that is suited to the water flush toilet commonly used in most Australian households. Septic tanks are the most common form of on-site wastewater primary treatment used in Australia (Beal *et al.* 2005; Goonetilleke and Dawes 2001; Graaff *et al.* 1980). Septic tanks treat wastewater through their acting as anaerobic sludge chambers where a limited digestion of organic matter occurs and solids are settled out of the discharged effluent (Goonetilleke *et al*. 1999; Mann 1979).

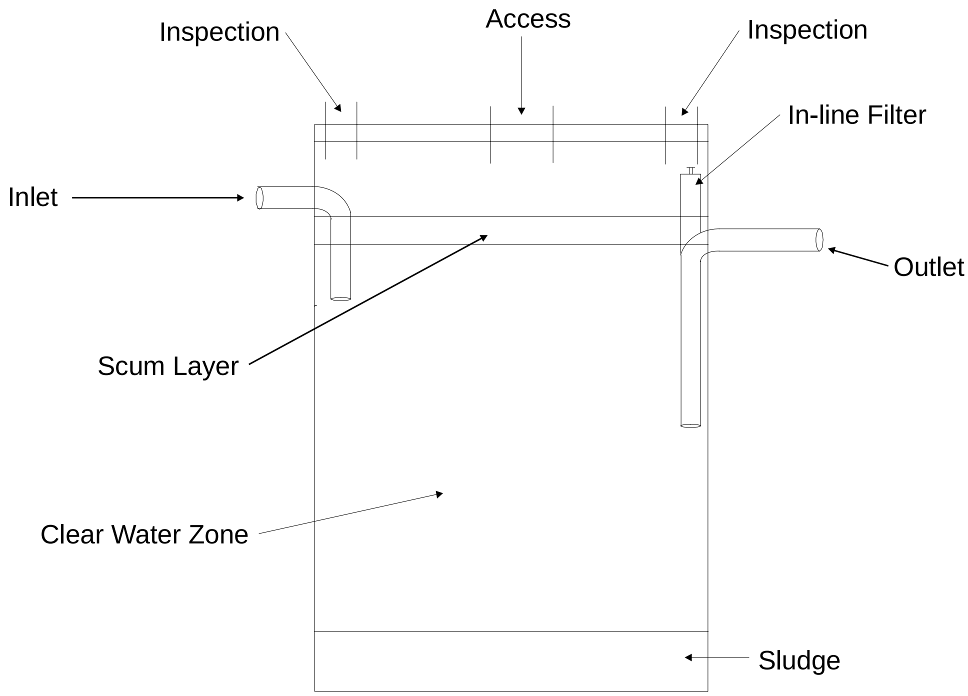
The treatment performance of septic tanks is influenced by:

- Size of the septic tank
- Design of the septic tank; such as the use of baffles
- Wastewater generation patterns – hydraulic surges
- Organic matter
- Presence of anti-microbiological agents; such as disinfectants
- Temperature
- Presence of oil, fats, and grease

Complied from (Goonetilleke *et al.* 1999; Mann 1979; McAvoy *et al.* 1998; Patterson 2003).

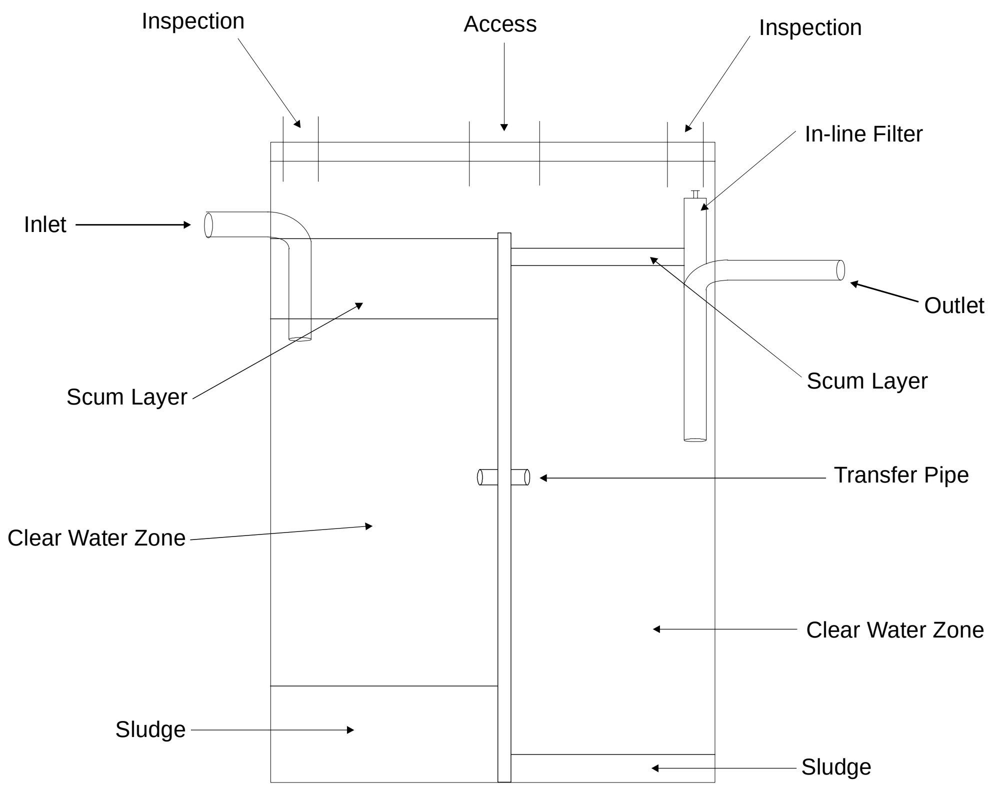
If a septic tank is undersized then poorly treated effluent may result, as the wastewater will not have been detained for a sufficient length of time within the treatment chamber (Panswad and Komolmethee 1997). The design of a septic tank has a great influence on how long effluent is contained within the tank. The basic septic tank design is presented in Figure 1.1

Figure 1.1 Basic Septic Tank Design



The settable solids leave the solution in the clear-water zone and settle out as sludge in the bottom of the tank. Lightweight material floats on top of the clear-water zone in a scum layer (Goonetilleke *et al*. 1999; Mann 1979). Preferably wastewater is contained within a septic tank for at least 48 hours before it is exported from the tank via the outlet (Crites and Tchobanoglous 1998). The septic tank design in Figure 1.1 is susceptible to shock loads of wastewater (high-volume, short period of time) that push effluent through the clear-water zone and out the outlet before it has reached a 48 hour retention time, often resulting in a higher solid concentration in the discharged effluent (CET 2001). Installing a baffle within a septic tank reduces the risk of such hydraulic short-circuits (Figure 1.2)

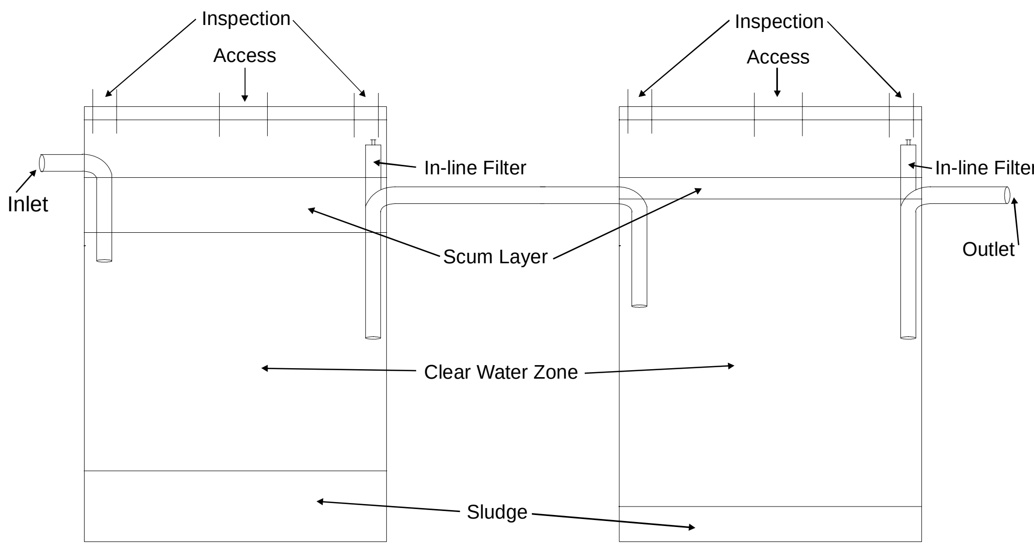
Figure 1.2 Baffled Septic Tank Design



Depending on the design, a septic baffle separates a tank into two or more chambers (Mann 1979). In the first chamber there is a greater accumulation of solids (Goonetilleke *et al*. 1999; McAvoy et al. 1998). The design of the baffle can also have a great influence. Crites and Tchobanoglous (1998) reported that a longitudinal baffle in a rectangular tank increased the detention time of the effluent within a septic tank when compared with the same size tank with a round tank with a central baffle. The effluent from the rectangular tank also had a smaller amount of solids (Crites and Tchobanoglous 1998). In times of large hydraulic surges, baffles can still fail if effluent is transported over the top of the baffle; this can have a large impact on water quality due to the large amounts of solid transfer in the scum layer

(CET 2001; Crites and Tchobanoglous 1998; Panswad and Komolmethee 1997). In the CET (2001) manual it states that dual septic tanks often provide the best treatment (see Figure 1.3).

Figure 1.3 Dual Septic Tanks



Dual septics are reported to lower the amount of solid discharge in effluent to an even greater extent than baffled septic tanks (Crites and Tchobanoglous 1998). There is debate as to whether higher quality effluent in dual septic tanks is due to the hydraulic flow-patterns between the two tanks or whether its simply installing two septic tanks often results in a greater septic volume and hence residence time (CET 2001; Crites and Tchobanoglous 1998).

All septic tanks require the regular removal of solids from the treatment chamber so that the clear-water zone is maintained. Periodicity of sludge removal depends on the amount of solids in the wastewater at the site but the tank should be de-sludged at least once every five years (CET 2001; O'Harms 2001). Gray (1995) and Goonetilleke and Dawes (2001) both reported that sludge accumulation that reduced the clear-water volume in a septic tank adversely impacted on the quality of the discharged effluent.

Many modifications have been made to the basic design of septic tanks to improve treatment performance (Cogger and Carlile 1984; Goonetilleke *et al.* 1999). Aeration is commonly applied in additional treatment stages; however calling the systems aerated septic tanks such as in Khalife and Dharmappa (1996) may not be appropriate as the terms are mutually exclusive. There are microorganism cultures available for sale that claim to improve the operation of septic tanks. The ‘effective microorganisms’ (EM) are generally marketed as having the potential to decrease sludge volumes in septic tanks and help produce a better quality effluent (Szymanski and Patterson 2003). Szymanski and Patterson (2003) conducted an evaluation study and found that there was no significant reduction in sludge production or noticeable increase in effluent quality, especially in regards to suspended solids in the discharged effluent, in EM dosed septic tanks. One technique that is effective in improving septic tank effluent is in-line filters (Fazio *et al.* 1993; Patterson *et al.* 2001). The filters are normally placed just before the outflow of the septic tank. The filters remove solids from the primary treated effluent and are effective at preventing solids from being exported from the septic tank during hydraulic surges (Panswad and Komolmethee 1997; Patterson *et al*. 2001).

The disposal areas for septic effluent are called by a variety of names, such as drainage fields, tile systems, sand trenches, absorption trench, soakage trench, evapotranspiration trenches and land application area (Beal *et al.* 2005; Kristiansen 1981; McGrath *et al.* 1991; Viraraghavan and Warnock 1976; Whelan 1988; WS/13/1 2000). A wide variety of designs and sizes are used throughout the world (Hoover *et al.* 1998; Yates 1986). The AS/NZS 1547:2000 has standardized the design for the construction and size of these trenches, defined as a land application area, in Australia and New Zealand (WS/13/1 2000). The major issue with septic evapotranspiration trenches is that many Australian soils are not suited to the long-term application of septic tank effluent (Beal *et al.* 2003; Dawes and Goonetilleke 2003; Patterson 1998; Yates 1986). The clay portion in many Australian soils is adversely impacted by the sodicity impacts caused by the application of septic tank effluent (Beal *et al*. 2003; Graaff and Patterson 2001). When an evapotranspiration trench fails effluent may come to surface or leach into the groundwater (Beal *et al*. 2003; Graaff *et al*. 1980). Evapotranspiration trench failure is of concern because it can have adverse impacts on public and environmental health (Cruz and Biggs 1998; Nellor *et al.* 1985). Along the eastern seaboard of Australia up to 80% of the soil types are unsuitable for the long-term application of septic tank effluent (CET 2001). In Western Australia the predominant sandy soil types are not impacted by sodicity; but problems do occur due to the movement of septic tank effluent into groundwater (Graaff and Patterson 2001; Whelan and Barrow 1984; Whelan 1986; Yates and Yates 1989). This is of particular concern if there are drinking wells close to septic system. The failure of septic evapotranspiration trenches has been a driver behind the development of on-site wastewater treatment technologies that produce a higher quality effluent.

1.1.6 Aerated Wastewater Treatment System (AWTS)

Wastewater that enters an AWTS is treated through an aeration process in a compact sewage treatment plant incorporated either in a plastic or concrete tank (Martin 2001). This treatment technique first began to appear commercially in the United States and the United Kingdom in the early to mid 1970's and in Australia in the early 1980's (Bailey and Wallman 1971; Brewer *et al.* 1978; Mann 1979; Martin 1999). Many different forms of this technology are available but there are two major generic treatment techniques (Dharmappa *et al.* 2001;Goonetilleke *et al.* 1999). In one class of AWTS the entire treatment process occurs under aerobic conditions, in the other an anaerobic process provides primary treatment before effluent enters the aerobic treatment components (Goonetilleke *et al.* 1999; Martin 2001).

Under normal operating conditions AWTS units produce a better quality effluent than septic systems (Martin 2001). A disinfection stage, generally comprised of a chlorine-based technique, allows for the surface discharge of the effluent with minimal odour and greater reuse opportunities (Devine and Waterhouse 1997). The oxidation of a high percentage of the organic matter reduces the clogging effect of the effluent and decreases the risk of soil seepage (Goonetilleke *et al.* 1999). The technology has proved to be popular with Schwizer and Davison (2001) reporting from a consumer survey that 40% of respondents who had recently constructed new dwellings had installed AWTS units. A survey of councils in the NSW conducted at the same time showed that 13% of all on-site systems in NSW are AWTS (Schwizer and Davison 2001). Schwizer and Davison (2001) did however state that the take-up rate of AWTS installation is lower than expected. Problems with the AWTS units have been reported in numerous studies (Goonetilleke *et al*. 1999). These issues concerned; long-term performance, maintenance, high operating costs, hydraulic surge susceptibility, sludge accumulation, salinity and sodicity (Beavers *et al.* 1999; Brewer et al. 1978; Geenens and Thoeye 2000; Goonetilleke et al. 1999; Hanna *et al.* 1995; Hoover *et al.* 1998 Khalife and Dharmappa 1996). The performance standard most frequently used in Australia is that developed by the New South Wales (NSW) Health Department and incorporated into the new AS/NZS standard. Grab samples are taken from the AWTS unit after the disinfection stage. The required quality of these samples is shown in Table 1.2

Table 1.2 NSW AWTS Performance Standard

Characteristic	Performance Criterion
Biochemical Oxygen Demand – five days (BOD_5)	<20 mg/L, with no sample >30 mg/L
Total Suspended Solids (TSS)	<30 mg/L, with no sample, >45 mg/L
Thermotolerant Coliforms	<30cfu/ 100 mL, with no sample, >100cfu/ 100 mL
Dissolved Oxygen	>2 mg/mL
Free Residual Chlorine	Between >0.2 mg/L and <2.0 mg/L

Adapted from NSW Health (1998) and AS/NZS(b) (2001).

In Australia major performance audits on AWTS units have been undertaken by regulatory bodies in Queensland by Beavers *et al*. (1999), Western Australia by Devine and Waterhouse (1997), South Australia by Kayaalp (1997), and New South Wales by Khalife and Dharmappa (1996). A high degree of non-compliance with the legislated performance requirements was found in these studies. New South Wales recorded a 96% failure rate for the required levels of free residual chlorine and South Australia had up to 89% failure rates (Kayaalp 1997; Khalife and Dharmappa 1996). In the 216 sites studied in Queensland, 68% of sites failed to meet one or more of the required performance milestones (Beavers *et al*. 1999). These reviews during the mid-to-late 1990's all have contributed to new provisions for AWTS in state legislation and the AS/NZS 1547 code.

Nonet (2004) has conducted a review of selected international legislation involved with the regulation of AWTS. The relevant codes from Australia, New Zealand, Germany, the Netherlands, Norway, United Kingdom, United States and Quebec, and the proposed European code were compared. Nonet (2004) reports that the proposed European Standard EN 12566-3 will be a marked improvement over the current myriad of legislation enforced over Europe and should reduce the number of poorly manufactured products. She however did identify several shortcomings in the new European code. These included; a relatively long test period of 36 weeks, a high cost associated with gaining system approval that will potentially limit small business access to the market, and very little focus on the after-sales servicing and long-term maintenance of the treatment system. Nonet (2004) indicated that the

AS/NZS 1547-2000 testing regime is only 26 weeks and manages to simulate longer-term operation through a sludge injection and recommended that this method be applied elsewhere. The American code ANSI/NSF 40-1999 legislates consumer protection with compulsory maintenance and emergency repair components as well as continued performance monitoring (Nonet 2004). While the Australian code does not specifically enforce licencing, maintenance, and emergency repair contracts some local government bodies have introduced by-laws requiring the AWTS units in their respective shires to fulfill these requirements (Hodges 2001). Hodges (2001) reported that a comprehensive licencing and enforced maintenance scheme had brought the AWTS units in the Beaudesert Shire up to a 90% compliance rate. In Australia, representatives of the manufacturing industry, institutions involved in on-site education, and certain state regulatory departments have all published papers aimed at achieving a more consistent and professional standard of AWTS maintenance (Martin 2003; O'Harms 2001; O'Keefe 2001). The next review of the AS/NZS 1547 code may examine the possibility of legislating more stringent licencing and maintenance requirements.

In Martin (2001) and Martin (2003) the author reported on the situation in New South Wales and claimed that prescriptive construction guidelines and performance standards are a step in the right direction but of very little value if the provisions are not enforced in the field. As President of the AWTS Manufacturers Association Ltd he stated that a cooperative approach between the regulatory bodies and the AWTS construction industry is required so that all parties, including the end point consumers get a 'fair go'. Flapper (2003) in her paper challenged the effectiveness of the AWTS guidelines in New South Wales stating that too much leeway had been granted to the manufacturers in regards to best management practice principles allowing a wide, and sometimes scientifically invalid approach to sampling procedure and statistical analysis. She also claimed that the guidelines ignored to a certain extent the realities of the practical application of AWTS units in the field and how they impact on the environment and the householder (Flapper 2003). Commenting on both Martin's and Flapper's papers, Gunn (2003) stated that both authors had valid arguments and that construction accreditation and field performance assessment of AWTS units need to be combined and incorporated into new more comprehensive guidelines.

The vast majority of publications that deal with AWTS units focus on problems encountered with the technology. Many of these problems such as susceptibility to hydraulic surges and insufficient chlorine can be solved through either construction change or an effective maintenance program (Dharmappa *et al*. 2001). Very few of the reported studies have examined the limiting factors associated with the reuse of the treated effluent on the soil. The treated effluent may contain nutrients, potential pathogens, heavy metals, chlorinated hydrocarbons, and because of the predominance of chlorine disinfection chambers used with AWTS units relatively high concentrations of salts and sodium (Gardner *et al.* 1997; Stevens *et al.* 2003). These limiting factors could have an adverse impact of the sustainability of the soil in the effluent irrigation area and need to be researched further (Balks *et al.* 1998;

Bond 1998; Gordon and Gardner 1996; Graaff and Patterson 2001; Roygard *et al.* 1999).

1.1.7 Reed-bed Filters

A reed-bed filter is a lined channel filled with an aggregate in which aquatic plants are grown (Ozaki 1999; Davison 2003). Primary treated effluent flows the reed-bed channel and is treated by the microorganisms that form biofilms in the aggregate layer and by the aquatic plants within the channel (Ozaki 1999; Peterson and Teal 1996). Most reed-bed filters that treat septic discharge do not have effluent exposed to the air; this is to do with public and environmental health. It is considered safer to have a horizontal sub-surface flow through the reed-bed (Davison 2001). Exposed effluent wetland types of wastewater treatment can be used for effluent that has undergone aspects of secondary and tertiary treatment (Davison 2001; Greenway and Simpson 1996; Machate *et al.* 1999; Tanner 1996). Davison (2001) reported that the advantages of reed-beds in on-site wastewater treatment are reduced maintenance, low-tech, small energy requirements, and resistance to hydraulic shock loads. The biggest disadvantage is a large environmental footprint. The aquatic plants in the reed-beds do not generally have the capacity to reuse all of the effluent through transpiration (Davison 2001; Karpiscak *et al.* 1996). The treatment given to the non-transpired effluent by the reed-beds does mean that a reduced land-application area is required for the disposal of the wastewater (Davison 2001; WS/13/1 2000).

1.1.8 Sand Filters

Sand filters are used to provide additional treatment to effluent that has been through a septic tank or AWTS (Goonetilleke *et al*. 1999; Kristiansen 1981; Schudel and Boller 1990). Sand-filters are of two main types (Boller *et al.* 1993; Soar and Tinholt 2003):

- Single pass
- Recirculating

Sand filters treat effluent through physical filtration, solid sedimentation, biofilm filtration, and chemical absorption. The chemical adsorption depends greatly on the media used within the sand filter. Different media, such as zeolite, scoria and clinoptilote can be mixed with sand in a filter to improve the removal through chemical absorption of certain nutrients (Geary *et al.* 2001; Saunders and Whitehead 2003). Review of the literature shows that single pass filters that receive controlled volumes of effluent in intermittent doses produce a better quality of effluent than single pass filters that were continually saturated with unregulated flows of effluent (Bellamy *et al.* 1985; Boller *et al*. 1993; Schudel and Boller 1990; Yahya *et al.* 1993). The pores between sand grains will clog over time, especially if the effluent contains a high concentration of solids (Avnimelech and Nevo 1964). While the clogging of the sand reduces the volume of effluent that the sand filter can treat in a given space of time; the clogged sand often provides a better quality of effluent, especially in terms of potential pathogens (Bellamy *et al*. 1985; Kristiansen 1981; Weber-Shirk and Dick 1999).

Recirculating sand filters are designed so that effluent will pass several times through the filter media. The number of cycles through the filter depends on the design of the filter and the hydraulic loading rate of the treatment system (Soar and Tinholt 2003). The recirculated effluent is quite often mixed with a small volume of new effluent (normally 4:1 ratio) (Goonetilleke *et al*. 1999). The recirculation of the effluent through the sand-filter increases the amount of treatment and may produce a higher quality of effluent than a single pass filter (Soar and Tinholt 2003).

The effluent treated by sand filters can be used for irrigation or if of sufficient quality for other types of reuse (Goonetilleke *et al*. 1999).

1.1.9 Peat Filters

Peat-filters are described as a type of bio-filter (Goonetilleke *et al*. 1999; Lens *et al.* 1994). Peat filters in Australian on-site wastewater treatment are mainly used to give additional treatment to septic tank effluent (Patterson *et al*. 2001). Patterson *et al.* (2001) reported that peat filters decreased nitrogen concentrations, faecal coliforms and phosphorus levels in septic tank effluent. It is acknowledged that the peat in the filter will eventually become exhausted, especially in for phosphorus adsorption (Patterson *et al*. 2001). Peat filters can produce a good quality of effluent, and reduce some of the adverse impacts to soils that occur with the long-term application of wastewater (Lens *et al*. 1994; Patterson *et al*. 2001). The ability to reuse peat filtered effluent in aboveground reuse applications is limited by a yellow-to light-brown discolouration that occurs from tannins leaching into the water.

1.1.10 Wastewater reuse

The irrigation of plants with wastewater is not a new innovation. The agricultural technique of adding human and animal effluent to the land as a watering method and an aid in maintaining soil fertility has been practised in Eastern Asia and the Western Pacific for over 4000 years (Asano and Levine 1996).

The use of wastewater for agricultural irrigation has been not been as popular in European Cultures as it is regarded as unsanitary (Monte 1996). The European colonisation of water scarce, soil poor countries, such as South Africa and Australia slowly began to change the European mind set on wastewater irrigation (Thoma *et al.* 1993).

In the last two decades the increasing scarcity of clean freshwater and the economic and environmental concerns of wastewater disposal has stimulated an increased worldwide interest in water related topics (Asano 1998). This has in turn led to a global upsurge in wastewater reuse, principally in Australia, China, Federal Republic of Germany, Guatemala, India, Indonesia, Israel, Mexico, Saudi Arabia, South Africa, and the United States of America (Tchobanoglous 1996).
Most countries have legislation/guidelines stipulating the level of treatment that wastewater requires before it reaches a quality considered safe for agricultural use

(Asano and Levine 1996; Bontoux and Courtois 1996). There is no accepted worldwide standard, and quite often what is established as a safe wastewater irrigation technique in one country, may be outlawed in another country as unsafe (Chang *et al.* 1996). Many countries have introduced, or are in the process of introducing legislation pertaining to the permissible levels of pollutants in wastewater for its disposal into the environment (Lock 1994).

The majority of research and development on wastewater irrigation schemes is carried out at the large scale, using municipal sized sewage treatment plants and broad acre cropping, or large constructed wetlands (Krofta *et al.* 1996). Environmentally sustainable industrial wastewater disposal is also developing into a more actively researched topic as environmental discharge legislation becomes stricter and more consistently enforced (Juanico 1993).

However most of the world's population does not have access to sewage treatment plants, and their sanitation requirements are met on-site. The World Health Organization stated that in 1988, 33% of the world's urban population did not have access to adequate sanitation, and in rural areas this figure jumped to 81% (Blumenthal *et al.* 1996). The global percentage of people served by adequate sanitation methods is actually decreasing. In 1990, 64% of the world populations were served by insufficient sewage treatment and disposal systems (Crook 1991; Tchobanoglous 1996). By 1994, this figure had increased to 66%. It is estimated by the World Health Organization that in the year 2000, this figure will rise to 68%, or in population terms, 3.31 billion people (Tchobanoglous 1996). The potential for infection from wastewater-borne diseases and parasites for this part of the population is considered high (Ashbolt 1997).

In many regions, especially rural areas without piped water, it is neither economically feasible nor practicable, to collect and process the effluent in large sewage treatment plants (Tchobanoglous and Burton 1991). However, on-site treatment, disposal, and even reuse of wastewater can be a viable economic and more importantly a hygienic approach to dealing with effluent produced by households or small communities (Geary 1992; McGrath *et al.* 1991). Wastewater treatment to a level where it is hygienic and has had its pollutant load reduced, whether on the large or the small scale takes time and costs money (Tchobanoglous and Burton 1991). Even when wastewater has had its pollutant load decreased, waste ion levels can still be high enough to cause the eutrophication of waterways and pollution of groundwater (Fourie and VanRyneveld 1995). It makes economic and environmental sense, therefore, to reuse this water again for another, ideally, beneficial purpose.

Reuse can take on many forms and need not be linked to agriculture. For example there is growing interest in the use of treated sewage effluent in power station cooling towers (Wijesinghe *et al.* 1996). Non-potable urban uses such as in air conditioners, fire sprinkler systems, and toilet flushing is also becoming more widespread (Asano 1998). Other wastewater reuse schemes include saltwater intrusion control, subsidence control, and even snow making (Shuval 2003). The irrigation of plants with wastewater remains very popular and despite several human health and environmental concerns, the different watering techniques can also have environmental, economic, and public/community benefits (Bond 1998; Crook and Surampalli 1996). The interactions between plants and wastewater have been studied at many different levels and from diverse angles. There are many factors that influence the relationship for example, plant species, wastewater quality, plant-growing media, irrigation method, and climate (Myers and Falkiner 1999). External factors such as socio-cultural aspects, environmental concerns, political decisions, and economic considerations can all influence a wastewater irrigation scheme (Ahmad 1991).

Wastewater irrigation studies are relatively unique in the fact that they generally aim to maximize plant water use (Stevens 1997). In contrast, due to the cost and relative scarcity of water most non-wastewater irrigation trials aim to maximize the water use efficiency, and thus plant maximum water usage rates are not researched (McGrath *et al*. 1991; Allen *et al*. 1998). As an exception, in water-poor environments, such as Israel, citrus is used extensively in wastewater reuse irrigation because of its water-use efficiency, that allows for much larger plantations per ML of irrigation wastewater (Rogers *et al.* 1983). In wastewater irrigation the broad aim is to have the maximum amount of treated effluent used by the minimum possible number of plants, in the smallest possible land area (Stevens 1997). This has meant more research into maximum water usage rate and plant planting density research has been undertaken. High wastewater application rates have in turn led to effluent being applied at environmentally unsustainable loading rates in many reuse projects in Australia due to the chemical characteristics of the treated water (Gardner *et al.* 1996). It has been found that numerous effluent reuse projects over-irrigate, thus resulting in plant health deficits and the escape of wastewater through runoff into the groundwater or surrounding waterways (Myers and Falkiner 1999).

1.2 Hypothesis

The research undertaken in this thesis was set up to test the following hypotheses:

1. That based upon simple engineering and biological principles a wastewater reuse system could be designed.
2. That plant-based wastewater reuse can be effective and sustainable.
3. That environmental impact of on-site wastewater treatment can be environmentally benign and without potential impact to human health.
4. That approval for use of the developed system could be obtained from the Queensland DNR& M and EPA.

Chapter 2 Site Descriptions

The author and his father, Gavin Kele, during the late 1990s, developed the original idea for the new on-site wastewater treatment technology at the family pre-cast concrete business (Kele *et al.* 1999; Kele *et al.* 2000). The family has been involved in the construction and installation of on-site treatment technology since the early 1930s. The vast predominance of systems that were constructed and installed were septic tanks, but the business also had some experience in building AWTS units under licence for other companies. There was awareness that many on-site systems had a history of failure and that new legislation was proposed that had the aim of improving on-site wastewater technology and treatment performance. Investigations and experience showed that the majority of on-site systems failed due to insufficient size of the treatment unit and inappropriate soil in the effluent application area (Graaff *et al*. 1980). The two major aims of the planned technology design were to greatly increase the effluent detention volume and to make the system independent of local soil types. The increase in hydraulic detention would make the on-site technology more resistant to the adverse effects of hydraulic surges and should through the 'rule of thumb' that detention time equals treatment improve system performance and effluent quality. Soils that are unsuitable for the application of effluent require various amendments to make them suitable (Barrow 1999; Bond 1998). The amount of work required to improve poor soils so that on-site effluent application is more sustainable is in most cases not practicable or economically feasible (Anderson *et al.* 1995; Myers and Falkiner 1999; Oliver 1997). The relatively large evapotranspiration areas for effluent application in poor soils recommended by the AS/NZS 1547:2000 (WS/13/1 2000) and the various state codes that follow its regulations do not provide for long-term sustainability. The larger application areas may give a longer operating life, but as the limiting factors, such as salts and sodium, are still present in the effluent and the soil is still inappropriate for wastewater irrigation the problem of soil health and long-term sustainability has not been solved, only delayed.

The conceived design involved conventional primary treatment connected to a contained recirculating evapotranspiration channel. A contained evapotranspiration channel increases the detention time as the effluent is treated and reused in a manner where under normal operating conditions effluent does not enter the external environment. Suitable soil for effluent application can also be imported into the channel; making the treatment and reuse area independent of the *in-situ* soil type. The recirculatory nature prevents the waterlogging of the soil in the channel as it allows non-transpired water to return to a holding tank that provides additional effluent storage. A trial of the design was installed at the pre-cast concrete factory and basic testing was undertaken. It was acknowledged from the beginning that the contained nature of the system may result in an adverse accumulation of one or more of the limiting factors associated with wastewater treatment and effluent reuse. Additional test sites and a more comprehensive testing regime were required.

At this stage, the Plant Sciences Group (PSG) of the CQU became involved with the experiment and a partnership was formed. Funding was sought from the Advanced

Wastewater Treatment Technology (AWTT) grant scheme sponsored by the Queensland Department of Local Government. The application was successful and additional partnerships were formed with the Broadsound Shire Council, Emerald Shire Council, Rockhampton City Council, and Livingstone Shire Council (Kele *et al*. 2000; Kele *et al.* 2001). The original basic design was examined and improved to overcome some infrastructure deficiencies and to incorporate up-dated legislative requirements, such as all-waste septic tanks. The Rockhampton trial site was expanded and five new trial sites were installed within the local shires with which partnerships had been formed. Additional funding was obtained from the Queensland Water Recycling Strategy (QWRS) and two trial sites were added, one in the Emerald Shire the other in the Broadsound Shire (Kele *et al.* 2001). A total of eight trial sites were installed over four local government jurisdictions.

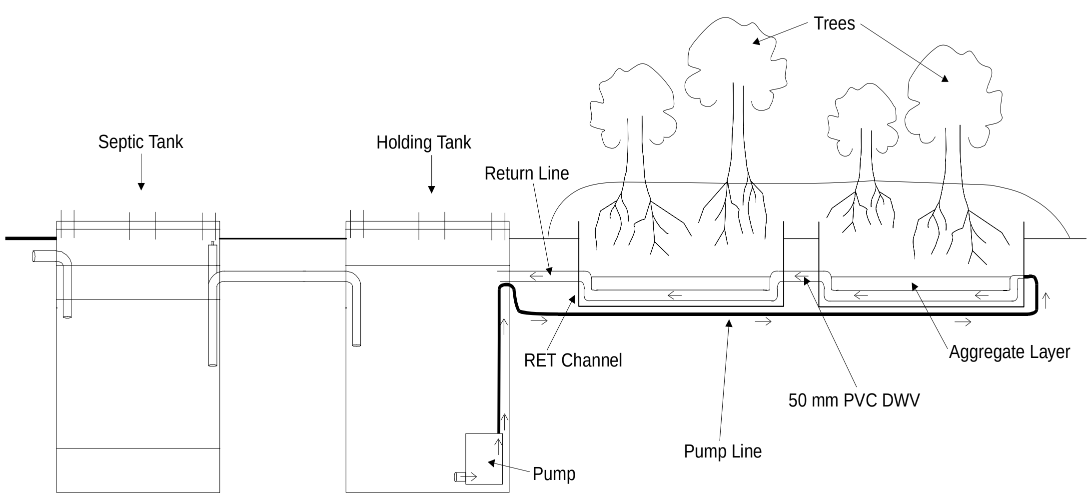
2.1 System Description

The on-site wastewater treatment system that should safeguard public health and meet ecologically sustainable development guidelines was designed and performance tested (Kele *et al.* 1999; Kele *et al.* 2000).

2.1.1 General Description

The wastewater generated at the research sites first undergoes primary treatment, either through an all-waste septic tank, or separately in a blackwater septic and a greywater vertical greasetrap tank. The primary treated effluent then flows through an in-line filter, to remove solids, and into a holding tank. The effluent from the holding tank is pumped, aerated by a venturi valve, and enters a self-contained concrete channel. The channels are comprised of a sequence of three metre long, 800 mm wide, 400 mm deep concrete pots and are connected by 50 mm pipe. Each concrete pot is installed level and sunk at least 200 mm into the ground. The specific numbers of pots used depends on the volume of wastewater generated at each site. A 50 mm slotted PVC pipe runs the length of the bottom of each pot. The pipe is surrounded by aggregate, which is designed to act as a gravel-filter and as a medium for a biofilm. This pipe is covered with approximately 60 mm of 10 mm aggregate. Terra-firma matting covers the aggregate layer and provides a porous barrier between the gravel-filter and the soil-bed. The channel is subsequently filled with a sandy-loam soil. Suitable soil can be imported for use in the channel if the soil at the site is inappropriate for the long-term application of effluent. The soil is mounded over the channel with the highest point of the mound being at least 200 mm over the top lip of the concrete pot. The channels are then planted with a selection of terrestrial plant species. The effluent moves, as it passes along the slotted PVC pipe, from the gravel-filter into the soil-bed, where it undergoes soil and rhizofiltration and ultimately is reused through transpiration. Any effluent not absorbed by the soil or reused by the plants returns with the flow from the channel to the holding tank. The holding tank has sufficient capacity to retain at least 48 hours worth of wastewater production. The holding tank incorporates a timer and alarm for the pump, a low-water trickle feed, and an emergency form of effluent disposal. The timer allows for the delivery of regulated doses of effluent to the transpiration channel at specific times to avoid continuous saturation of the soil. The alarm is fitted to give warning of pump failure. The low-water trickle feed is required so that in times of reduced wastewater production, sufficient soil moisture is retained to support growth of the plants. Keeping the soil moist reduces the risk of roots penetrating the terra-firma matting in search of water. In the event of system failure, such as pump breakdown, or excessive wastewater production, a safe temporary alternative for disposing of the excess effluent from the system is provided. The emergency effluent disposal can be in the form of a soakage drain or AWTS. The system meets the requirements for the treatment and subsurface reuse of on-site domestic wastewater according to the AS/NZS 1547:2000 and the Queensland on-site sewerage code. The technology will be referred to in this thesis, as the recirculating evapotranspiration trench (RET) system (see Figure 2.1).

Figure 2.1 Flow diagram of the treatment system



2.1.2 Primary treatment

Three methods of primary treatment were used throughout the trial, blackwater septic, vertical greasetrap, and all-waste septic (see Table 1.X). Different primary treatment methods were used due to changes in the relevant legislation and because some sites were retrofitted and had primary treatment technologies already installed. Sites constructed prior to the implementation of the AS/NZS 1547:2000 (WS/13/1 2000) do not have the all-waste septic tanks that this code requires.

The blackwater septic tanks handled all the wastewater produced by the toilet and bathroom hand-basins. The blackwater tanks were not connected to the kitchen sink, as this wastewater was classed as greywater for the purpose of the trial. The vertical greasetraps were connected to all the greywater producing facilities within the premises. The all-waste septic tanks treated both the black and the grey wastewater generated at the respective trial sites. The aim of primary treatment is to reduce solids, provide limited digestion of organic matter, a log reduction in faecal coliform numbers, and to produce a clarified effluent that can undergo further treatment (Crites and Tchobanoglous 1998; Goonetilleke *et al.* 1999; Yates 1986).

All types of primary treatment selected in this trial treat wastewater as unmixed anaerobic digesters. The vertical greasetrap was selected, as this technology is more resistant to hot-water hydraulic surges than is the shallow triple inceptor design greasetraps a hot-water surge can lift grease out of the treatment chambers and transport these unwanted solids into the next stage of treatment (Chu and Ng 2000; Kele *et al*. 2001).

2.1.3 In-line Filters

Zabel™ model in-line filters were installed in the outflow pipes of all the primary treatment tanks. Primary tanks that were 3000 L or less in size had the small style filter shown in Figure 2.2 and 2.3. Tanks with a capacity higher than 3000 L had a larger filter design installed. The in-line filters were installed as they remove some of the suspended solids found in primary treated effluent (Patterson *et al.* 2001; Patterson 2003).

The filters are located so that all effluent leaving the primary treatment chamber passes through them. The filter shown in Figures 2.2 and 2.3 is from the Rockhampton test site. This site had an industrial component that generated wastewater with large quantities of grease and oils. Figure 2.2 shows that the filter was able to remove some of the oil and grease from the primary treated effluent. A maintenance three-month cycle for the filter involved:

1. The removal of the filter from the outflow pipe
2. Washing the accumulated solids off the filter back into the main chamber of the primary treatment tank. Hot water was most effective though cold could be used.
3. Replacement of the filter in the outflow pipe

Figure 2.2 In-line filter after 3 months of operation

Figure 2.3 shows the in-line filter after solids had been washed off. The filters at all of the sites were washed every three-months. The filters were effective and no problems were recorded with their maintenance.

Figure 2.3 In-line filter after maintenance wash

The primary treated filtered effluent then entered the RET channel holding tank. The primary tanks and the holding tanks were connected with 100 mm PVC drainage waste and vent (DWV) pipe. This pipe was installed according to the relevant codes so that it gravity fed to the holding tank with a one-metre in 30 metre fall.

2.1.4 Holding tank

The size of the holding tank depended on the requirements of each specific site. The holding tank is constructed from a modified septic tank. The holding tank construction and structural integrity meets the requirements of AS/NZS: 1546 (AS/NZS 2001). The holding tank contains the primary treated effluent inflow, pump, pump timer, alarm, aeration system, return line, low-water trickle feed, backflow prevention device, and emergency overflow (see Figure 2.4). Each site had the holding tank specifically designed so that the holes that drilled through the walls for the various pipes minimised the number of bends and angles required by the pipework. The holding tank is the essential component of the recirculating treatment process. Effluent that is not transpired by the plants or detained in the RET channels returns to the holding tank. The effluent that returns from RET channels is contained within the tank where it mixes with new inputs of primary treated effluent. The holding tank has enough detention capacity to act as a wet weather storage facility. The mixture of effluent is then pumped through the RET channels.

Figure 2.4 Holding tank

2.1.4.1 Pump

A submersible electric sullage pump was installed in each holding tank. The size of the pump depended on the volume of effluent and the distance that it needed to be transported. The pumps that were selected had foreign object protection for the impellors and high quality watertight seals for the electrical connections. Three different brands of pumps were used in the trial, as not one brand had the complete range of pumps sizes with the desired characteristics. The effluent was pumped through 32 mm agricultural grade poly-pipe to the start of the RET channel. The pump line had a non-return valve installed.

2.1.4.2 Pump timer and alarm

Effluent was pumped to the RET channel when the pump was triggered by the pump time switch. The pump timer is located on top of the holding tank attached to the backflow prevention box (see Figure 2.4) The time-switch has a 24-hour cycle, with each hour split into four equal 15-minute segments. Under normal operating conditions the pump was run for 15-minutes every three hours. If the peak wastewater production times in the dwellings/facilities at the site were known the pump was set so that additional pumping-cycle occurred at these occasions. This potentially reduced the impacts of any hydraulic surges on the holding tank. Incorporated into the pump timer was a high and low-water alarm system. The alarm has a red flashing light as well as an audible component. Sensors in the bottom and the top of the tank triggered the alarm. The high water sensor indicated that the holding tank was full and the emergency overflow was in use. This would alert the householder or maintenance personnel to a possible pump failure. The low-water trickle sensor indicated that the holding tank was empty and that there was no water available to irrigate the plants in the RET channel. This sensor is designed to indicate a failure in the low-water trickle feed system.

2.1.4.3 Low-water trickle feed and backflow prevention box

The low-water trickle feed is designed to keep a minimum amount of water available for the irrigation of the plants in times of low or nil wastewater production. To maintain the biofilm on the aggregate and to keep the plant roots out of the pipework the bottom 150 mm of the RET channel must be kept saturated. If the wastewater production decreases, for example due to a close of business over a long weekend or a family holiday in a domestic dwelling, the low-water trickle feed allows water from a non-wastewater supply to enter the holding tank. A float that is situated 450 mm off the bottom of the holding tank triggers the low-water trickle feed. A backflow prevention box is situated on top of the holding to prevent any backflow and therefore contamination of the low-water trickle feed water supply with wastewater. The float results in the bottom 450 mm of the holding tank always having water. The height of 450 mm was selected as this height completely covered the pump. All sullage pumps have a float attached to them so that they are automatically turned off if the tank becomes empty. This prevents the pump from burning out. The height of the float on the pump was activated when there was approximately 150 mm of water left in the holding tank.

2.1.4.4 Return line

The return line enables non-transpired effluent to return from the RET channels to the holding tank. Where possible the RET channels are installed so that the lowest length of channel is closest to the holding tank; thus allowing the effluent to pass through the return line to the holding tank through the force of gravity. At the Rockhampton trial site this was not achievable and a powered form of return line needed to be installed. A pump-well was installed at the end of the RET channel system and the excess effluent was pumped back. The return line was constructed of 50 mm DWV PVC pipe in the gravity systems and 32 mm poly-pipe in the pumped. The return line enters the holding tank at a height just above the emergency overflow outlet. This means that the RET channel cannot be backfilled from the holding tank as effluent will flow through the emergency overflow before it can enter the return line. The return line was situated beneath an inspection port on the lid of the holding tank so that it was readily accessible for sampling.

2.1.4.5 Emergency overflow

An emergency overflow was installed at each trial site. Gravity fed soakage drains were used, as the emergency overflows are designed to operate when there was a power failure and the pumps could not operate. The soakage drain was designed according to the relevant legislation and constructed of 100 mm slotted DWV PVC pipe, aggregate, soil, and terra-firma matting (see Figure 2.5).

Figure 2.5 Construction of emergency overflow at Yaamba trial

The size of the soakage drain depended on the volume of wastewater generated. It was not economically feasible to install solar panels and battery back-ups to ensure that the pumps worked during power-failures. The emergency overflow could also divert wastewater out of the system during large hydraulic surges. The emergency soakage drain was not designed to dispose of wastewater on a regular basis and the hydraulic loading could not realistically be calculated; for this reason it was not designed according to the requirements of AS: NZS 1547:2000. The emergency overflow protected public and environmental health by keeping the effluent underground.

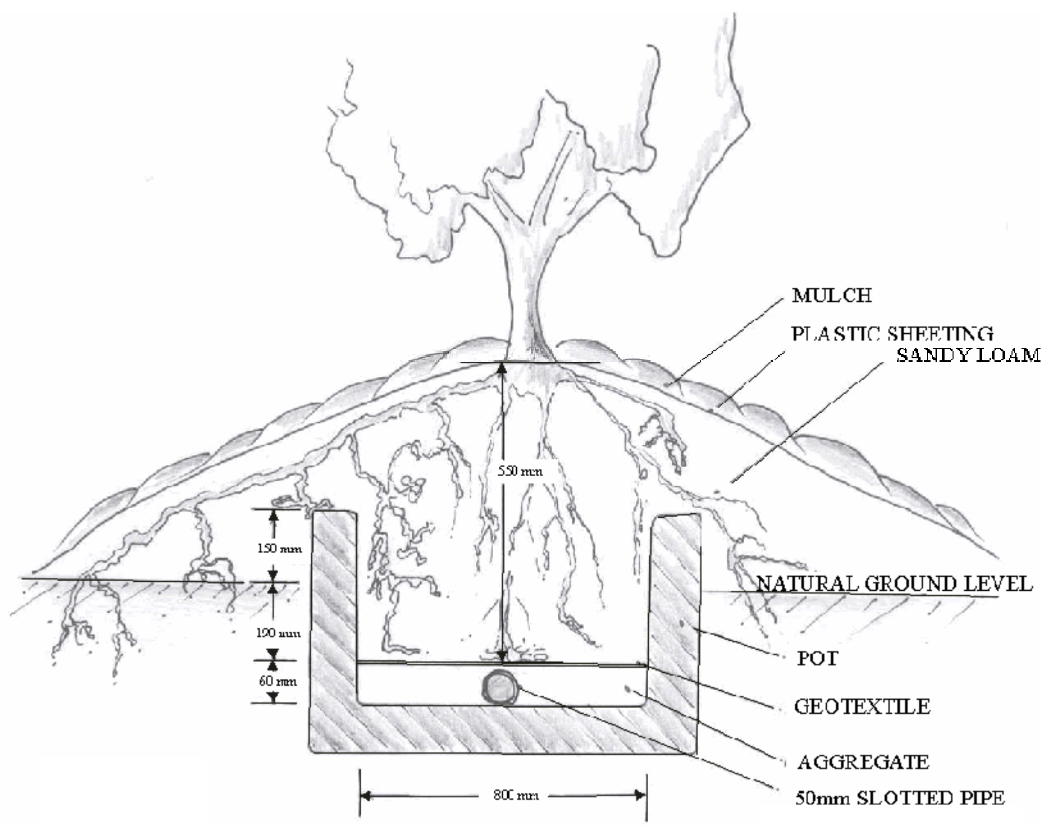
2.1.5 Aeration

As the effluent was pumped from the holding tank a venturi valve aerated the water. The effluent was aerated as a form of treatment and to prevent the saturated soil in the RET channel from becoming completely anaerobic (Kele *et al*. 1999; Matos and Sousa 1991). A venturi valve system was selected as it is powered by the pump and has few moving parts requiring maintenance. A tap was placed in the pipeline before the venturi valve, and by manipulating the flow of water through the tap the desired pressure required for the maximum aeration rate could be obtained. A TPS™ dissolved oxygen probe was used to calibrate this process. During the course of the trial it was found that having the tap and venturi valve outside the holding tank resulted in problems, most often through unauthorised human manipulation. The last two sites installed had the venturi valve and tap installed inside the holding tank. A vent, which went through the lid of the holding tank, was connected to the venturi valve, providing it with a clean source of air. At the end of the trial all venturi valves were altered to the *in-situ* holding tank design. The effluent after it had passed through the venturi valve entered the RET channel.

2.1.6 RET channel

The RET channel is comprised of several components that provide aspects of secondary and tertiary treatment, while also allowing the treated effluent to be reused through evapotranspiration. The channel is constructed from concrete and contains pipework, aggregate, terra-firma matting and/or geotextile, soil, plastic lining, mulch, and plants (Figure 2.6).

Figure 2.6 Cross-section of RET channel



RET channels were installed in two different patterns; a channel-to-channel flow-through and a herringbone central line feed design (see Figure 2.7 and 2.8). In the flow-through design effluent had to pass through one channel length before it could enter the next one in the series, and it has to flow through all of the channel lengths before it can return to the holding tank. In the herringbone design the channel lengths are installed level in respect to one another. A central feed line distributes the pumped effluent to each channel length. The central feed line is connected to the return line so that any excess effluent may go back to the holding tank. The central feed line means that the effluent does not have to pass through all of the channel lengths before it is able to return to the holding tank.

Figure 2.7 Herringbone RET channel design with central feed line

The herringbone design was trialled to establish whether the accumulation of limiting factors occurred more evenly through all the channel lengths. Both types of RET channel designs were filled with the same substrates.

At the start of the RET channel system a plastic fitting is emplaced that connects the poly-pipe to the 50 mm DWV PVC. A sample port was situated directly after this fitting and it was constructed from 50 mm DWV PVC using a tee-piece, a straight section of pipe (at least 200 mm long) and a cap. The sample port allowed direct sampling of the effluent before it entered the RET channel, as well as, a monitoring point for sludge accumulation in the pipework.

The RET channel system keeps the effluent isolated from the external environment while additional treatment and evapotranspiration occurs. It is important to note that the effluent is kept detained within the treatment system. Most older-style evapotranspiration trenches and effluent irrigation techniques are single pass, in the RET channel excess effluent is kept detained and recirculates through the system until it is reused.

2.1.6.1 Concrete Channel

The concrete channel used for the trial was an adapted cattle water trough. The internal measurements of the channels were 3100 mm long, 800 mm wide, and 400 mm high. This gave each concrete channel length a total volume of 992 L. Taking into consideration the aggregate and soil that fills the channel it was calculated that each concrete channel length could hold approximately 300 L of effluent under normal operating conditions. Concrete was used for construction so that adverse impacts from ground movement and plant root damage would be minimised. Concrete is not a watertight building material and it is acknowledged that a very small amount of effluent will pass through the concrete walls and into the environment. The physical filtration provided by the concrete walls should minimise the amount of potential pollutants released. Concrete is a standard construction material in the wastewater industry, especially in regards to septic tanks and AWTS tanks.

In the channel-to-channel flow-through installation pattern a two metre wide trench was excavated for the channel lengths. The depth of the trench depends on site-specific characteristics, although each channel must be placed at least 200 mm into the ground, preferably 300 mm. Each length of channel is placed on a bed of sand that is at least 100 mm deep. The sand bed minimises ground movement and provides a smooth surface so that the concrete length can be installed dead-level. While each channel length is installed level, gravity flow through the system occurs through emplacing each channel length downstream 25 mm lower than the previous length of channel. The pump in the holding tank pumps the effluent to the highest channel length and it then flows through the series of channels to the lowest channel length.

The herringbone design entails the required area to be leveled so that the channel lengths can be installed on a flat surface. The natural ground is covered by a level bed of sand at least 50 mm thick. The channel sections are placed onto the level ground with at least 2 metres space between them lengthwise. All channel lengths are checked with a spirit level to ensure that they are level.

2.1.6.2 Pipework

The effluent was pumped from the holding tank through 32 mm poly-pipe. After the effluent had passed through the Venturi valve aeration system it entered the RET channels through 50 mm DWV PVC. The RET channels lengths were connected to each other with 50 mm DWV PVC. A selected number of sample ports (construction explained in section 2.1.6) were installed between the channel lengths. The pipework between the channel lengths all had an expansion joint installed. These meant that if ground movement occurred; the risk of the pipework breaking was reduced. The expansion joint was covered with filter-sock to prevent small rocks from clogging the mechanism. To prevent leaks from the channels the pipework as it entered and exited had an O-ring installed and this was then concreted over. All pipework, both poly pipe and PVC DWV, exterior to the RET channels was surrounded by sand to minimise ground movement disturbance and to comply with relevant legislation (AS/NZS 2004).

The PVC pipe entered the channel at a height of 150 mm from the exterior base. The pipework then went through a series of bends and was directed down to the channel interior floor (see Figure 2.8). The pipework than ran the length of the channel. The 50 mm DWV PVC pipework along the channel bottom was slotted. All slots were on the bottom half of the pipe. In the channel-to-channel flow-through design the pipework rose through a series of bends at the end of the channel and exited at a height of 150 mm from the exterior base. In the herringbone design the channel was constructed with only one pipework access and the excess effluent exited through the entry point and went back into the central feed line. All the pipework within the length of channels was covered with a filter-sock. The filter-sock keeps solids within the pipe and potentially reduces the risk of the pipe-slots and the aggregate layer from clogging. The design of the RET system allows these solids to exit the pipework and return to the holding tank.

2.1.6.3 Aggregate

Within the RET channels the pipework is surrounded by an aggregate layer to a total depth of approximately 60 mm. The aggregate is composed of 10 mm blue metal stone. The role of the aggregate is to provide a medium on which a biofilm can form. The biofilm will provide additional filtration of the effluent and assist in nutrient transformation and use, as well as faecal coliform reduction (Abe and Ozaki 1999; Jantrania *et al.* 1998). The channel design is such that the aggregate layer will be permanently inundated with effluent.

Figure 2.8 Pipework and aggregate in RET channel-to-channel flow-through design

2.1.6.4 Terra-firma matting/Geo-fabric

The terra-firma matting was placed over the aggregate layer so that it completely covered the interior of the channel. The terra-firma matting was two metres wide and the excess width was smoothed down the outside of the channel. The aim of the terra-firma matting was to prevent the clogging of the aggregate layer with soil and to limit the possible intrusion of plant roots around the pipework.

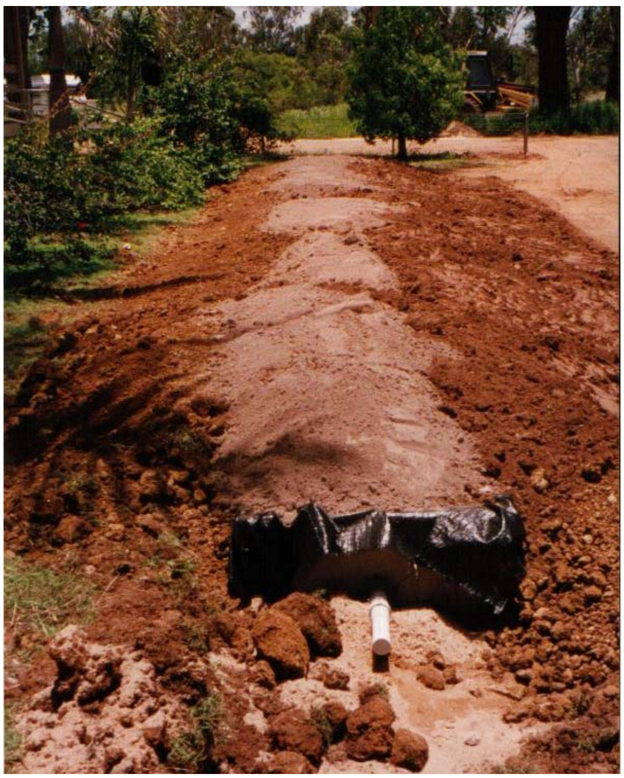
2.1.6.5 Soil

The soil within the RET channel is the single most important design aspect of the system. The selected soil type must be able to withstand the adverse impacts of pollutants, such as salts and sodium ions that are present in the effluent. In a closed recirculating system the factors that limit the sustainability of the soil will accumulate. The soil that is placed within the RET channels needs to have a minimum sustainable life of 15 years to meet the legislative requirements (WS/13/1 2000). Some soil types, such as heavy clays, are not appropriate for the long-term application of effluent, while others, like sandy loams, are more suitable (Bond 1998; Cajuste *et al.* 1991; Siebe 1995; Wolf *et al.* 1998). Soils that are resistant or tolerant to the impacts of salinity, sodicity, nutrients, and heavy metals provide a better substrate for wastewater treatment and plant growth (Balks *et al*. 1998; Whelan and Barrow 1984).

A sandy-loam soil blend with a small clay amendment was selected as the soil type for the trial. A sandy-loam is resistant to the adverse impacts of salinity and sodicity and allows for the accumulated salts and sodium ions to be readily leached out of the soil solution. The clay amendment is susceptible to sodicity but provides a substrate to which phosphorus can be adsorbed (Graaff and Patterson 2001; Nagpal 1986; Robertson *et al.* 1998; Wang *et al.* 1995). Due to economic realities and the distance between the various test sites it was not possible to source exactly the same soil blend from the same soil supplier for all sites. This meant that slightly different soil blends were used at each site as soil suppliers had varying definitions of a sandy-loam soil with clay amendment. A soil classification was determined and recorded for each specific site.

Figure 2.9 shows the soil blend in the RET channels and the natural soil type at the Anakie test site. The natural soil was a heavy red clay, and the difference between it and the sandy-loam blend placed within the RET channel can be clearly distinguished.

Figure 2.9 Soil filled RET channel at Anakie site



The excavated soil from beneath the RET channels is used to partly form the mound either side of the treatment system (see Figure 2.9). Additional fill was required at some sites to complete the sides of the mound. No requirements were placed on the soil type used as fill. The requirement for fill was dependent on the type of slope found at each specific site. The mound is constructed so that its highest point in the middle of the RET channel is at least 200 mm higher than the top lip of the concrete channel. The soil mound needed to have sufficient height for the plants to be able to put roots through it and into the soil outside of the channel.

Twenty kilograms of worms was added to the RET channel soil at each site. The worms were spread as evenly as possible between each channel section. The two species of worms were applied *Eisenia fetida* (Tiger) and *Lumbricus excavatus* (Blue). The main purpose of the worms was to help increase soil aeration, although other benefits, such as nutrient transformation through digestive processes may have occurred (Kristiana *et al.* 2004). It was not possible to assess directly what impact the vermiculture had on the wastewater treatment or the health of the soil.

2.1.6.6 Plastic lining

Black Visqueen™ 100 μm plastic sheeting (2 m wide) was used to cover the entire length of the RET channel. The application of the plastic lining was aimed at preventing rainfall intrusion into the channel and the subsequent flooding of the system. The containment design and the recirculatory nature of the RET channels does not allow stormwater to disperse easily from the system once it has entered the treatment cycle. The raised nature and sloped sides of the RET channel mound in conjunction with the physical barrier of the plastic lining will mean that the majority of the rainfall will runoff and not enter the system.

2.1.6.7 Mulch

Garden mulch was spread over the black plastic lining. This was done to protect the plastic from ultra-violet light degradation and to make the RET channel length visually appealing. The mulch was applied so that it was approximately 100 mm deep. After the mulch had been applied the RET channel had the appearance of a raised garden bed. The mulch needed regular six-month re-applications, as it degraded over-time. The mulch was obtained from local sources; lawn clippings and hay were most commonly used.

2.1.6.8 Plants

A wide selection of perennial terrestrial plants was used in the trial. Aquatic wetland plant species were not used. A mixture of endemic natives, natives, and exotic plant species were planted in the RET channels. No monoculture plantings were trialled. Monocultures can be more susceptible to the accumulation of limiting factors, and if the plant species undergoes a period of senescence during the year, this can result in a marked reduction in evapotranspiration rates (Allen *et al*. 1998; Myers and Falkiner 1999; Myers *et al.* 1996; Zhang *et al.* 1998). The mixture of plants that were selected for each RET channel system were intended to flower and fruit at different periods during the year. Many perennial plants have maximum water and nutrient utilization rates during their reproductive cycle (Hopkins 1999). The aim of the plant selection process was to have at least some of the species in the RET channel at the peak of biological activity at any one time. This type of planting model should result in more consistent water and nutrient usage rate throughout the year than what occurs in a monoculture system where there is quite often a specific seasonal peak (Myers *et al*. 1996).

No tall tree species were selected for the trial. The majority of plant species were small trees and shrubs that do not grow taller than five metres. The tallest plants grown were bamboos that had an expected growth height of 10 m. These plants may be tall but they have no large taproot. Some vines and groundcovers were planted. Necessary trellis and shading requirements were provided for those plants that required them. Most RET channel lengths were planted with two small trees/shrubs and four lower storey plants. Horticultural plants, such as citrus, were planted in the trial. A complete list of all plant species used and where they were planted is available in chapter five.

The planting procedures for RET channels was as follows:

- Clear mulch from area
- Cut plastic lining in an X pattern with a sharp knife
- Dig a hole to the depth required (follow plating instructions) the centre of the hole should be in the middle of the ‘X’
- Backfill hole and soak the area with water
- Place the cut edges of the plastic lining back over the exposed soil
- Replace mulch

The RET channels should look like normal raised garden beds after planting (see Figure 2.10).

Figure 2.10 St Lawrence recreation area RET channels after planting

2.1.7 Overall System Installation and Commissioning

All sites were inspected before any design plans were drawn. The inspections established what area was available, the slope of the land, and the wastewater generating infrastructure. Wherever possible the holding tank was situated at the lowest possible point available. The holding tank needed to have sufficient fall to allow gravity feed from the primary treatment tank/s. A fall of one metre in six was preferred although one metre in twelve is allowed under the relevant legislation (AS/NZS 2004). The location of the holding tank was important in determining the location of the RET channels. The most efficient design that requires the least number of pumps is where the holding tank is at the lowest point and pumps up to the start of the RET channel system which is at the highest point. With the holding tank at a lower gradient than the RET channel any excess effluent can flow back into the holding tank through a gravity feed return line. If a gravity feed return line is not available due to unfavourable site characteristics a pump-well needs to be installed. The first item to be installed was the holding tank. This required a hole being dug; either by a backhoe or excavator. After the holding tank was put into the ground the hole was three-quarters back-filled with sand, the inflow and outflow connections are left exposed. The sand minimises ground movement around the tank, this is especially important in regards to the pipe connections through the tank walls. The sullage pump was then set-up and the low-water trickle feed float calibrated. The tank was then half-filled with a non-wastewater source of water. The weight of the water inside the tank prevents it from floating if a wet weather event occurs.

Care was taken to ensure that the RET channels were set up to gather the maximum available sunlight, thus positively assisting evapotranspiration rates. This meant facing them in an east-west aspect and removing potential sources of shade. The area necessary for the RET channels is first cleared and the first concrete lengths are installed. In the herringbone design a flat pad is created. The flat pad is at least 250 mm below natural ground level and has 50 mm of sand covering the entire area. A laser-level and a two-metre screed were used to ensure that the pad was flat. All channel lengths are installed level to one another. Each individual channel length is also installed level. A straight board, at least two metres in length and a spirit level were used to ensure that each channel length was level and the same height as each other. The interior and exterior PVC DWV pipework was then installed. A spirit level was used to make certain the central feed line was level.

In the channel-to-channel flow-through design the first concrete length in the series was placed at the highest point. Each individual length itself was installed level. The next channel length in the series was installed 25 mm lower than the previous channel length. The fall was checked with a ruler, straight iron, and spirit level. The number of concrete lengths in a series can be determined by the fall available at a specific site. At some sites two or more channel sequences were installed so that the maximum and minimum recommended depths of the concrete lengths in relation to the natural ground level were not exceeded.

After the channel lengths were installed correctly the pipework within them and between them was constructed. The pipework was then covered with aggregate. The terra-firma matting was put in place and each channel was filled to the top with the sandy-loam soil. Care was taken not to bump and move the concrete lengths during this process. The effluent pump line (poly-pipe) from the holding tank was then connected to the venturi valve and then run-out and joined with the appropriate connecters to the start of the PVC DWV pipework that runs through the RET channels. The return line for excess effluent is then connected to the holding tank. The return line is then temporarily capped to stop water flow. Additional water (not wastewater) is added to the holding tank and the pump is turned on. The pipework leading to, through and from the RET channels is then checked for drips and leaks, any problems are then repaired. The blocked return line allows the water to accumulate in the channel lengths and completely saturate the sandy-loam soil. This causes the soil in the channel lengths to sink. Observation showed that it took approximately 6000 L of water to saturate the volume of soil contained in eight channel lengths. The channel lengths were then overfilled with sandy-loam soil by approximately 300 mm. The soil used for topping up was then left alone for at least six hours so that it could settle. During this time the pipework trenches were backfilled with sand, the primary treatment tanks were installed and connected to the holding tank and the emergency soakage drain was constructed. At the completion of these processes the remaining sand backfill was put around the holding tank. The block on the return line was removed at this time. After the soil in the RET channels had settled the worms were added and mounds either side of the concrete lengths was constructed. It is important at this point to mark exactly where each concrete length starts and finishes. The fill from the tank/s and RET channel pad/s excavations was used to build the mounds. Additional fill was generally required to assemble mounds that were at least three metres wide and 450 mm high. The highest point of the mound was the middle of the RET channel. The black plastic was then run lengthways over the middle of the mound completely covering the RET channel area. The mulch was then applied over the entire mound area. Using the marks that show where the concrete lengths start and finish, plants were transplanted. The larger plants where placed in the middle of the RET channel 500 mm from an end. Under-storey plants where put approximately 1/3 of the distance in from each end of the concrete length. After the planting was finished the pump was run once more and the venturi valve/s were adjusted and calibrated. Water flow back to the holding tank was checked at this time. Finally the warning effluent reuse, avoid contact signs were put in place. This completed the installation process.

Effluent was not pumped through the channels immediately. It was preferred for the system to have at least three days with no new water inputs. This allowed the saturated soil in the channels to drain and the microorganisms and plants some time to establish. When wastewater inputs began the pump's timer was setup. A standard pumping schedule was fifteen minutes every three hours. Note that the pumping schedule needed to be adapted to each specific sites wastewater generating characteristics. Three months after the site had been installed a check of the entire system was undertaken. Leaks and pipe blockages were looked for and any plants that had died were replaced; this completed the commissioning process.

2.1.8 Maintenance Requirements

There is no type of constructed on-site wastewater treatment technology that does not require some form of maintenance. The type and frequency of the required maintenance does vary between wastewater treatment techniques. The aim with the RET channel system was to minimise maintenance; especially that which required regular visits from specialised personal. No specialised parts are required to build a RET system all the components are available from a standard pre-cast concrete factory, plumbing store, garden nursery, or soil supplier. All maintenance and replacement of parts should be manageable by existing personnel; that is tank-pump-out services, licenced plumbers, and landscape gardeners. Unless the treated effluent is brought aboveground for reuse, no advanced disinfection stage is required, thus eliminating the need for the regular replacement of disinfection chemicals, UV light tubes, or electrodes. The householder or commercial operator is not required to perform any routine maintenance tasks.

The primary treatment tanks need to have the solids pumped-out when necessary; legislation states a minimum of once every five years. The holding tank should also be pumped-out at the same time. The in-line filters need to be washed out at least once every six-months, preferably every three-months if possible. The pumps need to be checked for clogging at least once every year; sullage pumps are susceptible to foreign object damage, for example human hair wrapped around impellors. The pump should be observed in operation and the return line should be examined to make sure that the excess effluent still flows back into the holding tank. The venturi valve should be checked for clogging and the accumulation of biofilms. The pump and the venturi valve should be cleaned of any accumulation that has occurred. A physical inspection of the RET channels should occur at least once every six months; physical integrity and plant health should be examined. The RET channels should be checked for leaks. Dead plants should be replaced; plants suffering from diseases or pests should be treated appropriately. If the plants appear to be suffering from water stress they may be pruned. A minimum three-yearly pruning schedule for all plants in the RET channel is recommended as it encourages new growth and prevents the plants from shading each other and reducing evapotranspiration rates. Mulch should be reapplied on a yearly basis; although some householders or commercial operators may prefer to perform this task using grass clippings regularly applied throughout the year.

In the long-term the owner of the system needs to be aware that electrical components such as the pumps have a limited life and will need replacement. Effluent uptake into the soil will in most instances slow over time due to the formation of biomats (Beal *et al*. 2005). This may reduce the evapotranspiration rate of the plants in the RET channel. Two biomats will form within the RET channel. One will form at the bottom of the RET channel, the other biomat forms at a higher point in the channel at the interface between the permanently saturated soil zone and the non-saturated soil zone. This biomat is constructed of plant roots and microorganisms and it slows the effluent absorption rate into the sandy-loam soil. The closed nature of the RET channel allows for a physical manipulation of the biomat not available in most other technologies. Compressed air can be introduced to the RET channel pipework through the sample ports. A compressed air blast can shift solid accumulations within the pipework back through the return line and into the holding tank. The compressed air also lifts the soil within the RET channel. The physical movement of the soil puts breaks into the biomat and increases the effluent flow rate into the soil column. This process requires an air compressor of at least 60 kPa pressure; preferably 100 kPa, and an air hose no greater than 40 mm in diameter. This particular form of maintenance may never be required, but it is available for use, and can increase the effluent uptake into the RET channel soil. When the tanks are pumped out a fresh-water flush (water low in salinity and sodicity) through the RET channels can leach out salts and sodium ions from the aggregate layer and the soil column. The removal of these limiting factors can increase the sustainable life of the aggregate, soil, and plants. This process can be performed by having the tanks pumped-out, filling the holding tank with fresh-water pumping it repeatedly through the RET channels and having the holding tank pumped out again the next day. The costs involved are the fresh-water, the electricity, and the pump-out. This process can be carried out as required. The soil and the plants in the RET channels will eventually need replacing. The system is designed to have a minimum operating life of 20 years. It is possible to remove the aggregate, pipework, soil and the plants from a RET channel, using machinery such as backhoe. It is then theoretically possible to add new aggregate, pipework, soil and to replant. The material removed from the RET channel would have to be disposed of to a suitable landfill. The concrete channel itself and the 'footprint' of the treatment system in the property could be reused again.

2.2 Site Descriptions

Eight trial sites were installed in this research project; the type of wastewater produced and the installation time of the treatment systems varied from site-to-site (see Table 2.1). One trial site was installed in Rockhampton city, one in Livingstone shire, two in Broadsound shire, and four in the central highlands of the Emerald Shire.

Table 2.1 General description of the eight trial sites

Site	Type of On-site Facility	Type of Wastewater	Date Installed	New/Retrofit
Rockhampton	Small-Industrial	All waste	June 1998	Retrofit
Yaamba Domestic	3-Bedroom	All waste	October 1999	New
St Lawrence Domestic	4 X 3-Bedroom.	All waste	November 1999	Retrofit
St Lawrence Recreation Area	Amenities Block	All waste	February 2001	Retrofit
Anakie	Small Retirement Home	Greywater	January 2000	Retrofit
Sapphire	Amenities Block	Blackwater + Chemical Toilet Dump	June 2000	New
Rubyvale	Amenities Block	Blackwater	April 2000	Retrofit
Gem-Air Caravan Park Willows	2-Amenities Block + Laundry	All waste	April 2002	Retrofit

The relevant local authority determined the EP rating for the each specific site. Different types of primary treatment were used; the type selected depended on what type of wastewater was produced and the original treatment technology present at the site (see Table 2.2). In retrofit installation the tanks that were already in-place were used wherever possible. The RET system has a greater volume detention capacity than most other on-site wastewater treatment and reuse technologies. Compared to an AWTS system the holding tank has a greater capacity due to the absence of dividing walls and internal substrates.

Table 2.2 Site EP rating and primary treatment type

Site	Equivalent Person (EP) Rating	Blackwater Septic	Vertical Greasetrap	All-waste Septic
Rockhampton	15	X	X	
Yaamba	10	X	X	
St Lawrence Domestic	40	X	X	
St Lawrence Recreation Area	80			X
Anakie	10		X	
Sapphire	19			X
Rubyvale	19			X
Gem-Air Caravan Park	100			X

In the eight sites the contained channel lengths increase the detention capacity by at least one-third, and in one case more than doubled the volume of effluent contained (see Table 2.3).

Table 2.3 Quantification of treatment detention volumes of the eight trial sites

Site	Greasetrap Volume (L)	Septic Tank Volume (L)	Holding Tank Volume (L)	Approximate Channel Capacity (L) [1]
Rockhampton	900	1800	900	3900
Yaamba	1800	1800	3000	2400
St Lawrence Domestic	4800	6400	6300	7200
St Lawrence Recreation Area	-	11 000	4500	7200
Anakie	1600	-	3000	2100
Sapphire	-	4500	3000	2400
Rubyvale	-	4500	3000	2400
Gem-Air Caravan Park	-	14 100	3000	20 000

[1] Assuming channel capacity is at least 1/3 of total volume

This is assuming that the maximum effluent volume per channel length is approximately one-third of its total volume.

No trial site was installed completely alike as specific site characteristics resulted in variations. As the research progressed lessons learnt from the previous installations helped refine and improve the technology. The specific site characteristics and any changes from the generic construction plan are explained in the following sections. The eight sites are described in the order in which they were assembled. A site diagram for each of the eight sites is provided in Appendix A.

2.2.1 Rockhampton site

This site was constructed in two stages. The treatment system was designed to treat the wastewater produced by a small pre-cast concrete factory. The wastewater was generated from three toilets, one urinal, three large sinks, and one wash down stations. The sinks and wash-down station do have volumes of industrial wastewater, such as grease and machinery oils, entering them. The 1800 L septic tank had been used at this location since the early 1950's. A special holding tank was built for this site; an 1800 L septic tank had a riser connected, increasing the detention capacity to 2500L, and a baffle spilt the tank in half. Figure 2.11 shows the one-half of the tank used a vertical greasetrap (on the left) and the other half as the holding tank (on the right). Three 100 mm PVC DWV pipes are visible in the holding tank side, the top-right pipe is the emergency overflow, and the other two are the inflow pipes for the primary treated greywater from the vertical greasetrap shown in the left-hand side of the figure and the blackwater from a 1600 L septic tank (not shown in figure). The curved pipeline carries the pumped effluent to the RET channels.

Figure 2.11 Interior of Rockhampton Holding Tank

The detention capacity of this tank is too small under the legislative requirements of new Australian and New Zealand standard (WS/13/1 2000). This tank was built before this standard was enacted; the design was not used at any other trial location.

Thirteen RET channels were installed at the site. The first five were constructed in 1998 according to the channel-to-channel flow-through design. The remaining eight were put in the herringbone design in late 1999. A diversion valve split the effluent equally between the two RET systems. All of the RET channels were installed over old concrete rubble and soft fill. The concrete factory is built over an old sandstone quarry that has been back-filled in over several decades. The location of the RET channels did not allow for a gravity powered return line. A pump well was located at the lowest point between the two RET systems. The pump-well had a total capacity of 800 L. A backhoe, bobcat and crane were used to build the RET system. The factory works between 7:00 am and 5:30 pm on weekdays; some weekend work, mainly on Saturdays, is performed with a reduced work-crew. The factory is supplied with reticulated town-water and untreated creek water.

2.2.2 Yaamba site

The Yaamba site treats and reuses the wastewater from a three-bedroom domestic house in the Livingstone shire. The channel-to-channel flow-through design was used for all eight-channel lengths. A backhoe and a bobcat were used to construct the RET channel system. Two people lived in the house, both of who performed shift work. The house was built using water efficient infrastructure. All drinking water was supplied from rainwater tanks. Some bore-water was available for some tasks, such as showers, but due to its high alkalinity could not be used in the hot water system or for washing clothes. The house-site was built over a magnesite ($MgCO_3$) ore deposit. When the holes for the tanks were dug the magnesite ore was found at approximately one metres depth. The overlaying soil had an average pH of 8.1 and the bore-water had an average pH of 8.3. The site took four people two days to install.

2.2.3 St Lawrence domestic site

The wastewater produced by four domestic three-bedroom houses was treated and reused by the RET system installed at this St Lawrence site. No water efficient infrastructure was present in the houses. There were four single flush toilets, four kitchen sinks, four dishwashers, four showers, four vanity units, four washing machines and eight laundry sinks. The houses were owned by the Broadsound Shire Council and are used to accommodate council employees and their families. All the houses were occupied, however some council staff spent weekends away from St Lawrence. Greywater from the houses was untreated and disposed of in adjoining parklands. The blackwater produced by the houses had in the past been treated by septic tanks and disposed of in evapotranspiration trenches. The septic tanks (1600 L) were constructed in the early 1960's. The main soil type is a compacted mudstone with less than 20 mm of topsoil. Council records show that explosives were used to excavate the holes for the septic tank installations. These septic tanks were pumped out and used for primary treatment in this trial.

The distance and the slope of the land between the four houses meant that the wastewater could not gravity feed to a central location. The two houses closest to the RET channels had their greywater piped to a 3000 L vertical greasetrap. The treated greywater was then piped to a 4500 L holding tank. The blackwater from the two septic tanks was piped directly to the 4500 L holding tank. Two houses were located lower than the RET system location. The greywater from these houses was piped to an 1800 L vertical greasetrap. The treated greywater and blackwater was piped to an 1800 L holding tank. This holding tank pumped the primary treated all-waste effluent to the 4500 L holding tank located adjacent to the RET channels. All primary treatment tanks had in-line filters installed.

Twelve of the RET channel lengths were constructed in the channel-to-channel flow-through design, and twelve in the herringbone. Each design was split in half to produce four separate RET systems of six channel lengths each. Two of each design was planted with medium to large plants, while the other two were planted with the same medium to large plants but with an under-storey of small shrubs, herbs, vines, and groundcovers. An identical planting scheme was used for each different design. The aim of this experiment was to assess the impact of an under-storey.

The site was constructed with a crane-truck, backhoe, and bobcat. Hindsight showed that excavator hire would have been cheaper as the mudstone hampered the digging progress of the backhoe. Torrential rain meant that installation work was extended by four days. The site took four people two weeks to construct. Logistics was an issue as St Lawrence is located approximately 200 km away from the nearest plumbing store and soil supplier.

2.2.4 Anakie site

The system at this site treated the greywater produced by the Anakie Retirement Home. There are six self-contained units at the retirement home. These units were fully occupied with a waiting list for places. All units are supplied with reticulated mains water from the Anakie water treatment plant. This water treatment plant supplies treated bore water. The greywater was collected from six showers, six hand-basins (vanity units), six laundries (washing machines plus tubs), and six kitchen sinks. No water-efficient infrastructure was installed. Note that the kitchen sink water under some legislation would be considered to be blackwater, at this site it was defined as greywater by the Emerald Shire Council. The greywater was treated by a deep vertical greasetrap installed in 1992. The greywater produced at this site was originally pumped through an irrigation line to a paddock opposite the Anakie Retirement Home. This pump-line was kept as the systems emergency overflow. The installation of this site took four people five days due to delays caused by wet weather. The work would have been completed in three days without the rain. The site was relatively flat with an average fall of one metre over twenty metres. The original soil on site was a red heavy cracking clay. A backhoe was used to construct the site. When the holding tank hole was dug, blackwater from the next-door neighbours yard flowed into the excavation. Investigation showed that a series of old tree roots that had partially decomposed and were acting as natural pipes allowing the blackwater to flow from the evapotranspiration channel in the adjoining yard. A clay cap was placed over the tree-roots entry point; but this is acknowledged as only a partial fix. In the installation a four-metre gap was put between the fifth and sixth length of channel to allow access path access to a set of steps. Wooden garden bed edging surrounded the channel mound.

2.2.5 Rubyvale site

This site is located at the Rubyvale Community Hall. The amenities block is the only public toilet available in Rubyvale. The amenities block contains one urinal, three hand-basins, and six toilets. The infrastructure is old and only one toilet is dual-flush. The site was supplied with treated town-water from the Rubyvale treatment plant. A bore supplies the water for the treatment plant. The Community Hall has an intermittent wastewater production pattern with occasional large hydraulic surges. The Community Hall is used as a library, and has weekly bingo and line dancing sessions. It is also used for community meetings and parties, such as weddings, and 21st birthdays. During the tourist season, buses use the amenities block for their passengers. Several local residents who do not have toilet facilities at their mining camps use the amenities for their daily ablutions. Two 1600 L septic tanks and a single evapotranspiration channel originally serviced the site. These septic tanks were removed and the 4500 L septic tank installed. The evapotranspiration channel had failed with a relatively large volume of surface pooling occurring. Two brolgas (large native wetland dwelling stork) had nested next to the surface pool and a neighbour had dug an irrigation ditch from the pool of poorly treated effluent to water their vegetable garden. The volume of the surface pool was estimated at over 1500 L. The soil at the Community Hall is predominantly very heavy clay that has previously been mined and has a poor structure in relation to drainage. A twenty-ton excavator and a bobcat were used for the earthworks at the site. The presence of large rocks and the steep slope slowed the installation at the site. The site took five days to install; this also included the construction of a new fence. A fence was required due to the nearby presence of large numbers of goats, cattle, and horses. The eight channel lengths were installed in the channel-to-channel flow-through design.

2.2.6 Sapphire site

An old amenities block was originally at the location; this was demolished prior to the RET system being constructed. A new amenities block was built at the property. The new block consisted of a waterless urinal, five 3/6 L dual flush toilets, and three hand-basins with controlled flow taps. A chemical toilet dump was also assembled. All the wastewater, including the chemical toilet dump waste, received primary treatment in the 4500 L septic tank. The block is supplied with treated bore-water from the Sapphire water treatment plant. This new facility is the only public toilet at Sapphire. The main users are passing traffic; however a water collection point is nearby, and a nearby public park is used for a weekend market on a monthly basis. Some local residents without toilet facilities in their own home do use the amenities block. Once a year the Gem-Fest tourist event is held, several hundred people a day use the facility during this week. A twenty-ton excavator and bobcat were used to assemble the RET channel system. The site was installed in three days. Four of the RET channel lengths were installed in the channel-to-channel flow-through design, the other four in the herringbone pattern. The site was constructed over the top of four old failed evapotranspiration channels from the old amenities block. The entire property, excluding the amenities block, had at one time been used as part of an evapotranspiration trench. Very little of the original soil remained in the top 500 mm of the site. The predominant soil type was heavy brown clay. A fence was constructed around the entire development.

2.2.7 St Lawrence recreation area site

The Broadsound Shire Council has a recreation area on the western side of St Lawrence. This location provides free campsites for travelers and has an area devoted to horse-sports, in particular polo-cross. There is an amenities block that contains one urinal, eleven toilets, eight showers, and six hand-basins. Wastewater generation is variable with large fluctuations in the flow making calculating an EP difficult. There are more visitors staying in the recreation area during the cooler months, with peaks of over 100 people per day recorded by the council. Horse-sports functions may have over 500 people in attendance. The Broadsound Shire Council experimented with locking the amenities block and providing portable toilets during horse sport events. This did not prove to be successful as the doors to the amenities block were forcibly removed and the block used more frequently than the portable toilets. During the warmer months the recreation area may be empty, with only a few people staying in any given week.

Wastewater was treated at the site by an all-waste 11 000 L baffled septic tank, then by a 4000 L AWTS. The treated effluent was then pumped along a surface irrigation line 80 m long with the excess effluent pumped an additional 300 m into a Class A Fishery Reserve. The AWTS system was undersized, especially as the baffle walls and incorporated media walls, pumps, aerator, and disinfection technology reduced the effluent detention volume of the tank. The AWTS tank was susceptible to hydraulic surges and did not cope during high occupancy periods. The AWTS maintenance contract had been cancelled by the council and several adjustments to the system were made. The aerator was altered so that it was twice the size and operated 24 hours per day. An overflow was put onto the AWTS system so that it pumped excess effluent back into the septic tank.

The RET system was constructed to increase the wastewater treatment capacity of the amenities block. The primary treated all-waste effluent went from the septic tank into a 4500 L holding tank. The holding tank had the venturi valve incorporated within it. The effluent was then pumped through 24 RET channels installed in the channel-to-channel flow through design. There were twelve channel lengths constructed in a one series, plus two series of six channels lengths each. Twelve of the channels were planted with bamboo species. Six bamboo species were used, three clumps of each species were planted in two of each channel lengths. The RET channels were built over reclaimed saltpan. Approximately 120 tons of additional fill was brought to the site to provide additional soil over the built-up area. The fill was a mixture of soil types.

Excess effluent from the RET flowed back into the holding tank and any overload there went into the AWTS system. The surface irrigation system was disconnected and a sub-surface drip-line installed. The number of plants and the length of the irrigation line were tripled. The overflow into the fish reserve was disconnected. The maintenance contract for the AWTS was reinstated.

2.2.8 Gem-Air caravan park site

The Gem-Air caravan park is situated in the Willows gem fossicking area approximately 85 km west of Emerald. The total visitor capacity of the park is variable due to different numbers of people staying at each caravan site. There are forty moveable van sites, four permanent van sites, and four cabins. When the park is full there are normally about 100 people staying in the park. Very few tourists stay at the park during the warmer months. Over 95% of site rentals occur during the cooler months; March to September is considered to be the tourist season. The wastewater produced at the site is generated from two amenities blocks and a laundry. The site contains two urinals, ten toilets, three washing machines, six hand-basins, three laundry sinks, and ten showers. In the past the wastewater was treated in all-waste septic tanks and piped to the southern end of the caravan park. The primary treated effluent then flowed over the ground and into a water storage used by the park. This was not considered to be best practice by either the new owners of the park or the Queensland EPA.

The Willows is a drought prone area and at the time of the RET system construction was drought-declared. Tourists travel to the Willows to fossick for gemstones, mainly sapphires. Fossicking requires water to wash off the soil overburden. Fossicking water does not need to be of a potable standard. The RET system at the

Gem-Air caravan was designed with additional treatment stages so that some of the treated effluent was of sufficient quality to use aboveground in the fossicking process. The original all-waste septic tanks were used for primary treatment. The primary treated effluent from these septic tanks was piped to an additional 4500 L all-waste septic tank. This dual-septic tank process reduced the adverse impacts of shock loadings and increased detention time. All septic tanks had in-line filters. The effluent from the 4500 L septic tank gravity fed to a 3000 L holding tank. The holding tank had an internal Venturi valve.The RET channels used at this site were of a special design. There was at the site on average less than 40 mm of topsoil. Underneath the topsoil is an unknown depth of solid sandstone. A thirty-ton excavator with a rock-pick attachment (see Figure 2.12) was required for any earthworks.

Figure 2.12 Digging RET channels in sandstone at Gem-Air caravan park

Placing a concrete channel length inside of a solid sandstone excavation was deemed to be excessive. Instead four channels were dug in the sandstone. These channels were approximately twelve metres long, two metres wide, and 0.6 metres deep. This meant that each channel had approximately 14.4 kL total capacity. The bottom of the channel excavation was covered with 100 mm of sand (see Figure 2.13). The aim of the sand layer was to protect the pond-liner from any damage from rocks. The pond liner covered the channel excavation and the immediate top external environment (see Figure 2.13).

Figure 2.13 RET channels at various stages of construction at Gem-Air caravan park

Within the channel 100 mm PVC DWV pipework was used. This pipework was not continuous throughout the channel. A break was put in the pipework in the middle of the channel. This meant that the effluent had to leave the pipe and travel through the aggregate layer. No effluent can use the pipework as a hydraulic short-circuit and travel through the pipework and back to the holding tank without passing through at least one type of RET channel substrate. A 10 mm white stone incorporating 5 mm red zeolite chips was used for aggregate. The aggregate layer was 80 mm deep. The terra-firma matting was placed over the aggregate. A sand layer 100 mm deep was put over the terra-firma matting. The sand is not adversely affected by salinity and sodicity and should help prevent clogging of the terra-firma matting, while also providing a more permeable substrate when the biomat forms. The channels were then filled with a red sandy loam with a clay amendment. After the effluent had passed through the RET channel system it went to a 2500 L tank. This tank collected effluent so that it could be pumped through a recirculating sand and zeolite filter. The internal dimensions of the sand and zeolite filter were approximately 3.9 m wide, 6.4 m long, and 1.8 m deep. This gave it a volume of c. 44.9 kL. Effluent was pumped to the filter and distributed through 20 mm PVC pipes lain through slotted 100 mm PVC DWV (see Figure 2.14). The filter is constructed of different grades and/or sizes of sand and red zeolite. The effluent is distributed over the top of the filter and flows down through the various layers and is then collected into a pump well. The filtered effluent is then pumped to another 2500 L tank. This tank pumps the filtered effluent back through the sand and zeolite filter. Automatically every sixth pump cycle the treated effluent was pumped through a bromine-chlorine disinfection unit into a 22 000 L storage tank. Figure 2.15 shows some of the tanks at the Gem-Air wastewater treatment system.

Figure 2.14 Recirculating sand-filter showing effluent distribution system

Figure 2.15 Gem-Air treatment tanks

The disinfected effluent was reused in the fossicking process by the residents in the park and by the owners of the Gem-Air for irrigation of the park. The system was designed so that excess effluent from the tourist season could be stored and used to irrigate the plants over the warmer months. At the end of each tourist season the plants growing in the RET channels were heavily pruned. This reduced their evapotranspiration rates during times when limited wastewater was produced at the site as well as encouraging new growth and nutrient use.

The site took almost one month to install. The hire of the thirty-ton excavator used the machinery budget and this resulted in the sand, aggregate, soil, and zeolite being shifted by shovel and wheelbarrow. The fractured sandstone rock and left over zeolite chips were used to landscape the site (see Figure 2.15).

The Qld EPA issued a licence for this site. It is the only on-site wastewater treatment and reuse system approved by the EPA that allows treated effluent to be reused in gemstone mining.

2.3 Statistical Design

There are many uncontrollable variables between the eight trial sites that influenced the experimental outcomes; hence it was not possible for them to be statistically compared. The sites had somewhat different weather; they treated diverse types and volumes of wastewater, they had different soil types placed within the RET channel lengths and all sites had different soil types external to the RET channel lengths. Statistical comparison between the sites is not recommended.

However, analyses and evaluations were undertaken to determine how effective each site individually meets the legislative requirements required for on-site wastewater treatment and reuse systems. In addition, potential limiting factors, specifically nutrients, heavy metals, chlorinated hydrocarbons, salinity, and sodicity were examined so that a through assessment of the sustainability of the system can be made. Care was taken whenever possible to make sure that the results obtained from a specific site could be compared with other data acquired from that site. The experiments and the samples collected at each site were undertaken according to standard methods and best-practice techniques to ensure statistical accuracy (Haas 1993; Petrie and Diplas 2000; Tillett 1993; Zar 1984). The results from the evaluations performed during this research project will be described on a site-by-site basis.

Chapter 3: Water Quality

The nutrients, microorganisms, dissolved oxygen, salinity, pH, temperature, heavy metals, and chlorinated hydrocarbons in the treated effluent of the RET systems were examined. It is important to note that under normal operating conditions there is no discharge point and the treated effluent was to be reused within the RET system, except at the Gem-Air site. The design of the treatment system meant that primary treated wastewater entering the holding tank was mixed with returned non-transpired effluent that had undergone secondary and aspects of tertiary treatment in the RET channels. The mixture of different grades of effluent within the system created difficulties in the actual determination of the treatment classification of the RET technology. The ratio of primary treated wastewater to non-transpired effluent in the holding tank when any single test was performed could have been a major factor on the water quality. This ratio could change rapidly depending on the wastewater generation patterns and the evapotranspiration conditions. The trials undertaken to establish the water quality performance capabilities of the RET system were adapted to suit the recirculating nature of the treatment cycle. Long-term accumulation studies were performed at all sites to establish how effective the RET system was at treating the effluent over time. The eight sites were established at different times over a three-year period at geographically and functionally diverse locations hence each dataset from the individual locations were analysed discretely. The Gem-Air caravan park site did have a discharge point for the aboveground reuse of treated effluent, and the effluent at this point was also assessed and reported separately. The general aim of the water quality assessment trials was to determine the various parameters over time and to judge how the accumulation or the deficit of these factors would affect the operation of the RET system and its sustainability.

3.1 Nutrient Levels

The RET system is a closed recirculatory structure, except at the Gem-Air site. Because of this there was concern that the nutrients present in the effluent, if not removed through biofilms and plant growth, may accumulate in the effluent over time. To test whether nutrient ions were accumulating, the effluent in the holding tank was examined.

3.1.1 Materials and Methods of Nutrient Ion Accumulation Study

Measurements of nitrate (NO_3^-), ammonia (NH_4^+), phosphate (PO_4^-), and potassium (K^+) ions were made on samples taken from the holding tank at each of the eight sites. An additional set of samples was taken from the disinfected effluent holding tank at the Gem-Air caravan site. Samples were taken four times per year, at three monthly intervals. A 100 ml sampler was used to take two samples, one at the top of the holding tank the other 500 mm above bottom of the holding tank. The effluent from the holding tank was combined into a 200 ml composite sample. The samples were collected and transported to the laboratory at 4°C, all samples were analysed in the Belmont laboratory of CQU within 36 hours of being taken. The samples were thoroughly mixed using a bench-top vortexer at maximum speed for at least twenty seconds and the concentration of the ions was measured by a Merck RQflex reflectometer (model # 16970) using the methods described in Kleinhenz *et al.*

(1997). This process involved test strips being dipped into prepared effluent samples, allowed to develop and assessed colormetrically. Each test required 5 ml of effluent to be placed into a 15 ml tube. A reagent was added to the effluent and then after a specified reaction time a test strip was put into the mixture. Each nutrient had a specific test strip, NO_3^- (cat# 116971), NH_4^+ (cat# 116992), PO_4^- (cat# 116978) and K^+ (cat# 116970). Each nutrient test strip had a specific range, some effluent samples needed to be diluted and others a set volume of nutrient added to be able to determine the nutrient ion volume in the effluent. Each nutrient ion test was repeated. An average reading was recorded as the 3-monthly value. The values were reported as the yearly averages of the quarterly reading (n=4) and statistical tests were not used to compare sites.

3.1.1.1 Rockhampton Site

The average nutrient ion readings in the holding tank over five years are presented in Table 3.1.

Table 3.1 Average nutrient concentrations in the holding tank at the Rockhampton site

Test	1999	2000	2001	2002	2003	Standard Deviation
NO_3^- mg/L	2	3	3	2	3	1
NH_4^+ mg/L	16.2	65.5	52.5	49.0	32.5	19.1
PO_4^- mg/L	43.5	33.0	29.5	32.0	27.5	6.2
K^+ g/L	0.29	0.32	0.28	0.28	0.23	0.03

No trend was evident across the five years of the testing, although ammonia did show substantial year-to-year variation. Nitrate is a form of nitrogen that is readily accessible to plants and as such this may be the reason that it did not accumulate over the 5-year study, confirming other reports such as that by Davidsson and Leonardson (1996). Ammonium levels fluctuated substantially, with the peak levels being recorded when the employment numbers at the concrete factory increased, and decreased when fewer personnel were employed. Input levels of ammonia were relatively high, close to the concentrations reported in Surmacz-Gorska *et al.* (1997), as the blackwater was not diluted with kitchen waste or hand-basins, but came entirely from the toilets. Ammonium in the system must have been microbiologically oxidised, for it did not steadily increase over time as new inputs were added (Surmacz-Gorska *et al*. 1997). Phosphate and potassium levels did not accumulate in the effluent. Initially potassium ions did increase but over the final three years concentrations were smaller than the original value. As plants used the nutrients that were originally present in the soil, they were most likely replaced by ions in the effluent solution. At the Rockhampton site, no wastewater generation normally occurred during the weekends or public holidays as the factory was shut.

3.1.1.2 St Lawrence domestic site

Four years data on the average nutrient ion reading in the holding tank are presented in Table 3.2.

Table 3.2 Average nutrient concentrations in the holding tank at the St Lawrence domestic site

Test	2000	2001	2002	2003	Standard Deviation
NO_3^- mg/L	2	1	2	1	1
NH_4^+ mg/L	32.0	41.9	19.5	11.7	13.4
PO_4^- mg/L	103.5	98.2	87.5	84.2	9
K^+ g/L	0.38	0.14	0.12	0.12	0.13

There was no accumulation of nitrate ions. Ammonia ions peaked in 2001 then approximately halved in each succeeding year. The concentration of phosphate ions at this site was very high. The soil placed within the RET channels was purchased from Sarina and prior to purchase had been amended with bagasse, a by-product from the sugar refining process. Bagasse contains relatively large amounts of carbon and phosphorus. It appeared that phosphate ions diffused out of the RET channels soil into the effluent.

The phosphorus ions in the effluent slowly decreased in concentration and new inputs through wastewater generation did not appear to add to the concentrations of ions in the holding tank. The plant growth requirements may have caused a decline in the total phosphate ions in the system. Potassium ion concentrations decreased over time, and stabilised in the last two years. The occupancy rate of the four houses was constant; with some changes in individual tenants, but not in number of long-term tenants.

3.1.1.3 St Lawrence recreation area

When the first sample was taken in 2001 the system was still undergoing the commissioning process and wastewater had only been present in the holding tank for two weeks.

Table 3.3 Average nutrient concentrations in the holding tank at the St Lawrence recreation area site

Test	2001	2002	2003	Standard Deviation
NO_3^- mg/L	1	<1	<1	<1
NH_4^+ mg/L	29.4	21.5	8.9	10.3
PO_4^- mg/L	31.5	11.7	6.0	13.4
K^+ g/L	0.26	0.11	0.08	0.1

Nitrate ions were present in 2002 and 2003 but they averaged less than 1mg/L. This site had the greatest potential to produce plant biomass. The 24 clumps of bamboo grew quickly, and may have been responsible for the very low concentrations of nitrate ions and phosphate. Bamboo requires relatively large amounts of nitrogen for leaf growth and phosphorus for stem and root growth (Kleinhenz and Midmore 2001). A clay amendment was added to the RET channel soil at this site. The clay may also have adsorbed some phosphate ions. Ammonia and potassium ions decreased over time from the original value.

3.1.1.4 Gem-Air caravan park

Tables 3.4 and 3.5 show the data obtained from the RET channel holding tank and disinfected effluent holding tank respectively. The first samples taken in 2002 were during the commissioning process and wastewater had only been present in the system for one week.

Table 3.4 Average nutrient concentrations in the RET channel holding tank at the Gem-Air caravan park site

Test	2002	2003	2004	Standard Deviation
NO_3^- mg/L	1	1	1	0
NH_4^+ mg/L	45.8	44.6	56.9	6.8
PO_4^- mg/L	14.8	12.8	9.8	2.5
K^+ g/L	0.10	0.07	0.09	0.02

There was higher percentage of primary treated effluent present in the holding tank water at this site than at other sites. The design calls for at least half of the non-transpired effluent, that is the effluent that has passed through the RET channels, to be diverted to the recirculating sand and zeolite filter instead of back into the holding tank. Nitrate ions did not accumulate and remained at low concentrations. Ammonia ions did increase over time, however 2004 was a year with increased occupancy rates (15.2% over the tourist season) in the park.

This included a slightly higher occupancy rate outside of the normal tourist season. This increased the summer month ammonia ion concentration compared to what it had been in 2002 and 2003. The phosphate ions did not accumulate. The increased volume of primary effluent in the holding tank could have shown a relatively high quantity of phosphorus; but this did not eventuate. The owners of the park only supply detergents that were low in phosphorus and sodium. This may, in conjunction with the clay amendments to the RET channel soil, account for the reduced amounts of phosphorus. Potassium ions remained at low concentrations throughout the trial period.

Table 3.5 Average nutrient concentrations in the disinfected effluent holding tank at the Gem-Air caravan park site

Test	2002	2003	2004	Standard Deviation
NO_3^- mg/L	7	9	9	1
NH_4^+ mg/L	8.7	6.9	7.1	1
PO_4^- mg/L	9.9	8.7	7.0	1.5
K^+ g/L	0.06	0.05	0.05	0.01

Compared to the treated effluent in the RET channel holding tank the nitrate ion concentrations increased and the ammonia ions decreased in the disinfected effluent holding tank. Through cation exchange the zeolite could have absorbed some ammonium ions. The sand and zeolite may also have been used as a biofilm medium for microorganisms involved in the nitrogen cycle. This would have resulted in ammonia being microbiologically oxidized. Nitrate would then accumulate in this part of the treatment chain, as there were no plants to remove it. Phosphate and potassium ions slowly decreased over time from the 2002 reading. These ions may have been used by the microorganisms in the biofilm and taken up and transformed into the microbial biomass, or in the case of potassium ions exchanged by the zeolite.

3.1.1.5 Sapphire site

The four years' data on the average nutrient ion reading in the holding tank are presented in Table 3.6. Only two sample runs were conducted for the year 2000 average reading.

Table 3.6 Average nutrient concentrations in the holding tank at the Sapphire site

Test	2000	2001	2002	2003	Standard Deviation
NO_3^- mg/L	9	11	14	18	3.92
NH_4^+ mg/L	32.8	29.8	28.6	32.9	2.2
PO_4^- mg/L	67.4	71.8	74.7	88.4	9.1
K^+ g/L	1.4	2.92	3.1	3.9	1.04

This site had a chemical toilet dump attached to the septic tank. Strong acids, and high concentrations of salt and sodium went to the treatment system through the chemical toilet dump. Many of the plants (72%) in the RET channels died when the accumulation of pollutants in the effluent and in the soil became phytotoxic, microbiological activity at this site was not completely impaired. A thick crust formed in the septic tank and microorganisms were found in the effluent (see 3.2.6) Nitrate ions increased over time within the holding tank, while ammonia ions did not show a strong accumulation trend. It appears that ammonia was microbiologically oxidized, and the poor plant health may have resulted in the long-term small nitrate accumulation. Both phosphate and potassium ions increased in concentration. The reduction in plant productivity may be in part responsible for this accumulation. It is unknown what chemicals were added through the chemical toilet dump. Many different brands of chemical toilet reagent are available and it is possible that some of these contain quantities of phosphorus and potassium.

3.1.1.6 Rubyvale site

In Table 3.7 data are presented that show the average nutrient ion reading in the holding tank over four years. Three sample runs were conducted for the year 2000 average reading.

Table 3.7 Average nutrient concentrations in the holding tank at the Rubyvale site

Test	2000	2001	2002	2003	Standard Deviation
NO_3^- mg/L	2	1	1	1	<1
NH_4^+ mg/L	32.6	24.5	21.8	18.9	5.9
PO_4^- mg/L	14.6	12.9	12.9	10.8	1.6
K^+ g/L	0.21	0.23	0.19	0.22	0.02

Nitrate and ammonia ions decreased over time. Phosphate ions did not accumulate. This was the first site where a clay amendment was added to the RET channel soil. The potassium ion concentration did not substantially decrease during the course of the trial. This may have been because the concentration of potassium in the RET channel soil was relatively high (see Table 4.14). Potassium ions were not found in elevated concentrations in the potable water supply (average reading <0.1 g/L). Plant growth at this site was slowed by damage caused by heavy frosts that occurred during the commissioning process, however the plants did recover during the summer of 2000/2001.

3.1.1.7 Anakie site

Average nutrient ion reading in the holding tank over four years is presented in Table 3.8.

Table 3.8 Average nutrient concentrations in the holding tank at the Anakie site

Test	2000	2001	2002	2003	Standard Deviation
NO_3^- mg/L	<1	<1	<1	<1	<1
NH_4^+ mg/L	2.2	2.8	1.9	1.1	0.7
PO_4^- mg/L	25.5	22.9	31.9	27.4	3.8
K^+ g/L	0.28	0.32	0.19	0.13	0.09

Low concentrations of ammonia and nitrate ions were predominately due to the site treating only greywater. Greywater normally has only low concentrations of ammonia and nitrate ions, unless certain types of cleaners are used (Tchobanoglous and Burton 1991; Zeeman *et al.* 2000). Phosphate and potassium ions showed no accumulative trend. Potassium ions may have decreased in 2002 and 2003 as the plants matured and started to flower and fruit, both processes that require potassium (Smart *et al.* 1996).

3.1.1.8 Yaamba site

The four years' data for average nutrient ion reading in the holding tank are presented in Table 3.9. Nitrate did not accumulate. Ammonia fluctuated slightly but showed no marked increase in concentration. Phosphate ions decreased during the course of the trial. At this site potassium ions did accumulate.

Table 3.9 Average nutrient concentrations in the holding tank at the Yaamba site

Test	2000	2001	2002	2003	Standard Deviation
NO_3^- mg/L	2	1	1	1	0.5
NH_4^+ mg/L	23.1	18.9	17.8	20.0	2.3
PO_4^- mg/L	16.4	12.8	10.9	9.8	2.9
K^+ g/L	0.45	0.54	0.53	0.57	0.05

The underground water supply, which provided approximately 60% of the water that entered the treatment system, had elevated potassium concentrations that ranged between 0.32 and 0.65 g/L, whereas most potable water supplies have potassium concentrations of less than 0.15 g/L (Lock 1994). The area was close to magnesite, feldsparthic, and serpentinite rock and/or ore deposits and these may have leached potassium into the bore-water. The concentration of potassium in the effluent had not reached a point where it was phytotoxic (Hopkins 1999).

3.1.1.9 Discussion of Nutrient Ion Accumulation Study

It would have been beneficial to obtain total nitrogen (TN) and total phosphorus (TP) results for the study in addition to the nutrients examined. This would have given a more detailed analysis of the changes in nutrient concentration. The trial sites showed that the type of water supplied; such as groundwater, to each site was a contributing factor, especially in regards to potassium. This is important to consider as many wastewater treatment and reuse systems are designed with an assumption that the quality of the properties water supply will not have an impact. The type of wastewater produced, that is blackwater, greywater, or all-waste, and the ratio between the different types of wastewater had a major impact on nitrate, ammonia, and phosphate ion concentrations. The study showed that a wide range of nutrient concentrations was present between the sites and site-specific factors, such as the chemical toilet disposal at Sapphire, had major impacts on certain nutrient ion concentrations. At no site did nutrients accumulate to toxic levels. At most of the sites additional inputs of the selected nutrients could have been added as fertilizers as concentrations were at small values, for example potassium ions at the Willows site. The St Lawrence Domestic site showed that the addition of large concentrations of phosphate ions to the soil had a marked impact on a recirculating technology such as the RET system. In a single pass system an addition of nutrient ions to the evapotranspiration area would not have resulted in any changes to the effluent quality in the holding tank. As the RET system does recirculate, care needs to be taken with soil amendments to ensure that leaching and return of chemical elements to the holding tank does not have any adverse impacts. Overall this experiment showed that the nutrient ion concentrations between the sites was highly variable but at no stage reached phytotoxic levels.

3.1.2 Temporal Dissipation of Nutrients

The nutrient accumulation study focused on the effluent in the holding tank. To determine what inputs of nutrients occurred and how they impacted on the different stages of the RET system a trial was conducted at the Rockhampton site. The study was performed twice and conducted over 100 hours on each occasion. The first trial occurred in December 1999 and the second in December 2000. The aim was to establish the concentration of nitrate (NO_3^-), ammonia (NH_4^+), phosphate (PO_4^-), and potassium (K^+) ions in the various treatment stages of the Rockhampton site RET system and how they varied over a 100 hour period. Note that in December 1999 there were fifteen employees. This fell to twelve during the 2000 study.

3.1.2.1 Material and Methods of Rockhampton Temporal Dissipation of Nutrients Trial

Samples were taken from eleven different locations at the Rockhampton site as follows:

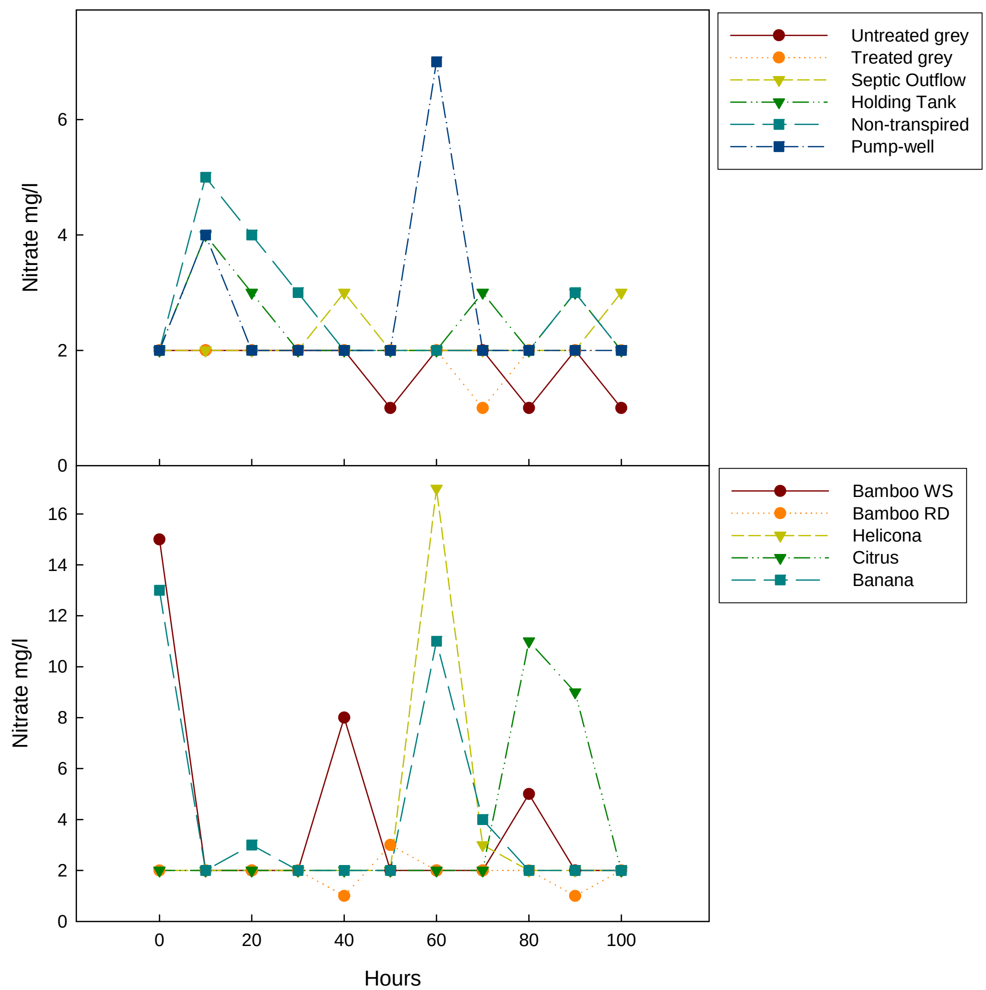
1. Untreated greywater – taken from the top of the vertical greasetrap
2. Treated greywater – taken from the discharge point of the vertical greasetrap
3. Septic – taken from the discharge point of the septic tank
4. Holding tank – taken from 500 mm off the bottom of the holding tank
5. Non-transpired effluent – taken from the return line from the RET channels
6. Bamboo WS – herring bone RET channel planted with bamboo closest to workshop
7. Bamboo RD - herring bone RET channel planted with bamboo
8. Heliconia – herring bone RET channel planted with Heliconias (gingers)
9. Citrus – channel-to-channel flow-through RET channel planted with citrus
10. Banana - channel-to-channel flow-through RET channel planted with banana (4th channel on site map)
11. Pump-well – taken from 500 mm from the bottom of collection tank for the non-transpired effluent prior to it being pumped back to the holding tank

The RET channels had sample collection ports located at the end of each of the selected lengths constructed from DWV PVC. Samples were collected from the relevant tanks and RET channels in 100 ml sterile containers, and stored and transported at 4°C to the Belmont Laboratory at CQU. All samples were analysed using a Merck RQflex reflectometer within 48 hours following the method described in section 3.1.1.

3.1.2.2 Nitrate 100 Hour Nutrient Variation Study at Rockhampton site

The nitrate ion results for the eleven test points in the two 100 hour nutrient trials are presented in Figures 3.1 and 3.2. In the untreated greywater and treated greywater the nitrate ion concentration never did rise above 2 mg/l. Overall the untreated greywater sample which was taken from the top of the vertical greasetrap had a smaller concentration of nitrate in both years. Either the nitrate ions were not present in same concentration in the top layer of effluent in the greasetrap or some microbiological oxidation of ammonia was occurring in the clear water zone that resulted in slightly higher concentrations of nitrate ions in the treated effluent. In the septic tank discharge the nitrate ions concentrations in December 2000 averaged 3 mg/l, which was slightly higher than the 2.1 mg/l December 1999 average. What caused the increase in nitrate ions is not known. The nitrate ions in the holding tank did not go above 3 mg/l in either year. The non-transpired effluent was collected from the return line discharge point into the holding tank, while the pump-well effluent was taken directly from the collection tank at the end of the RET channel system. Both types of effluent were non-transpired effluent from the RET channel system. The difference between the two-wastewater types was that the sample labeled non-transpired had been in the pipe between the pump-well and the holding tank since the last time the pump in the pump-well had been active and had not been mixed with any new inputs of excess effluent from the RET channels.

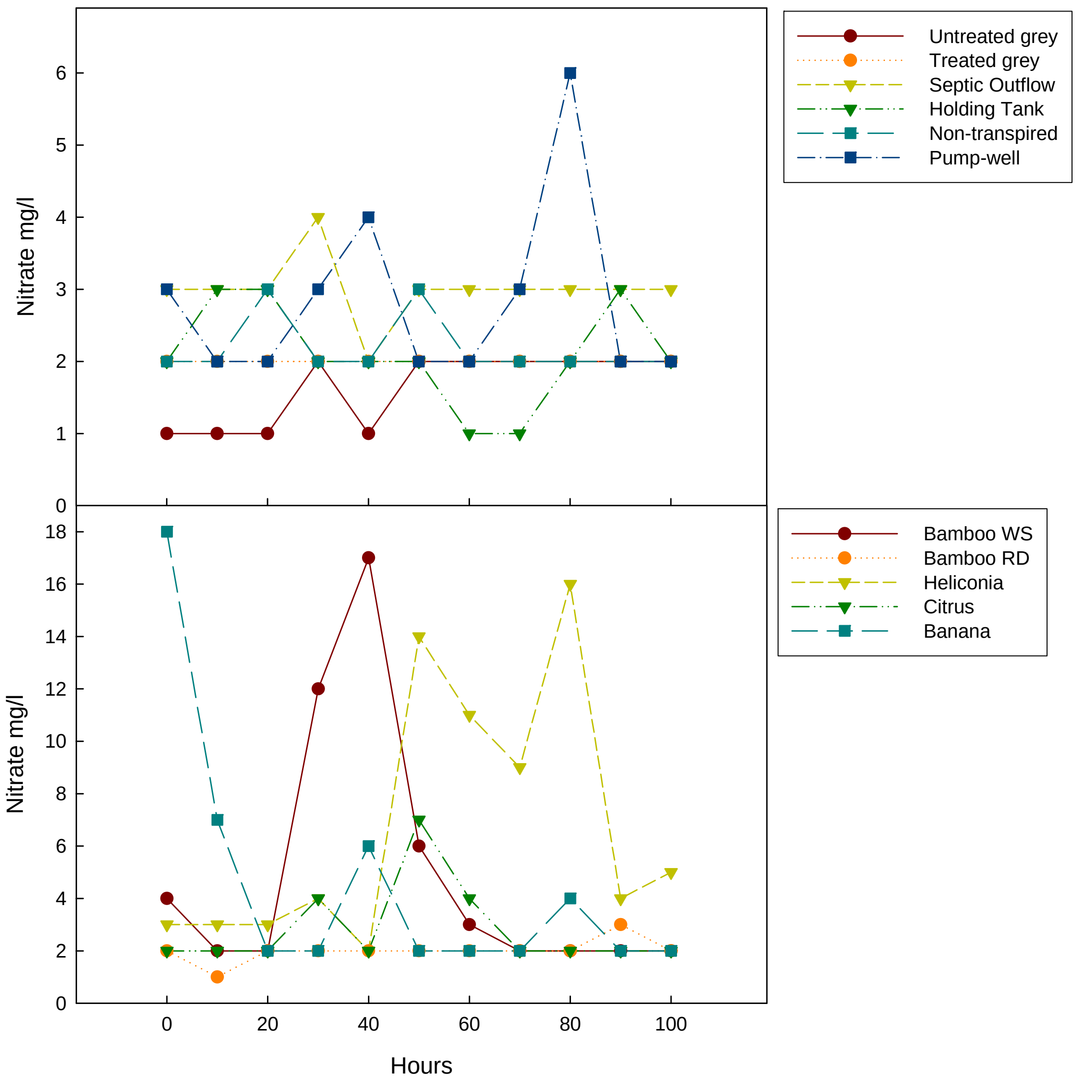
Figure 3.1 Nitrate ion concentrations in the Rockhampton RET system over 100 hours in December 1999



The pump-well sample had a mixture of excess effluent from the RET channel systems that may have entered the pump-well at anytime since the last time the pump in the pump-well was activated. Both the pump-well and non-transpired effluent had instances in each year where the concentration of nitrate ions was higher than in the holding tank effluent. This is indicated that microbiological oxidation of nitrogen had occurred in the RET channels and that some of the nitrate had been transferred to the excess effluent. Further evidence for this supposition is provided by the data from the RET channels. Over the two trials all the RET channels showed nitrate ion concentrations higher than that found in the holding tank effluent that was pumped to the RET channels. The nitrate ion concentrations in the RET channels showed marked variation. The bamboo WS, bamboo RD, and heliconia RET channels were constructed in the herringbone design, while the citrus and banana were channel-to-channel flow-through design. All the RET channels had the same soil type. Bamboo WS, and bamboo RD were both planted with three clumps of *Bambusa oldhamii,* and were at the start of the herringbone system. The heliconia channel was two rows back in the herringbone system. The citrus channels was the 2nd length and the banana channel the 4th length out of a total of five lengths in the channel-to-channel flow through design.

Bamboo WS and bamboo RD received concurrently approximately equal quantities of effluent pumped from the holding tank. The nitrate ion concentrations between the two channel lengths varied markedly. The bamboo WS had noticeably higher concentration of nitrate ions than bamboo RD even though they received the same effluent.

Figure 3.2 Nitrate ion concentrations in the Rockhampton RET system over 100 hours in December 2000

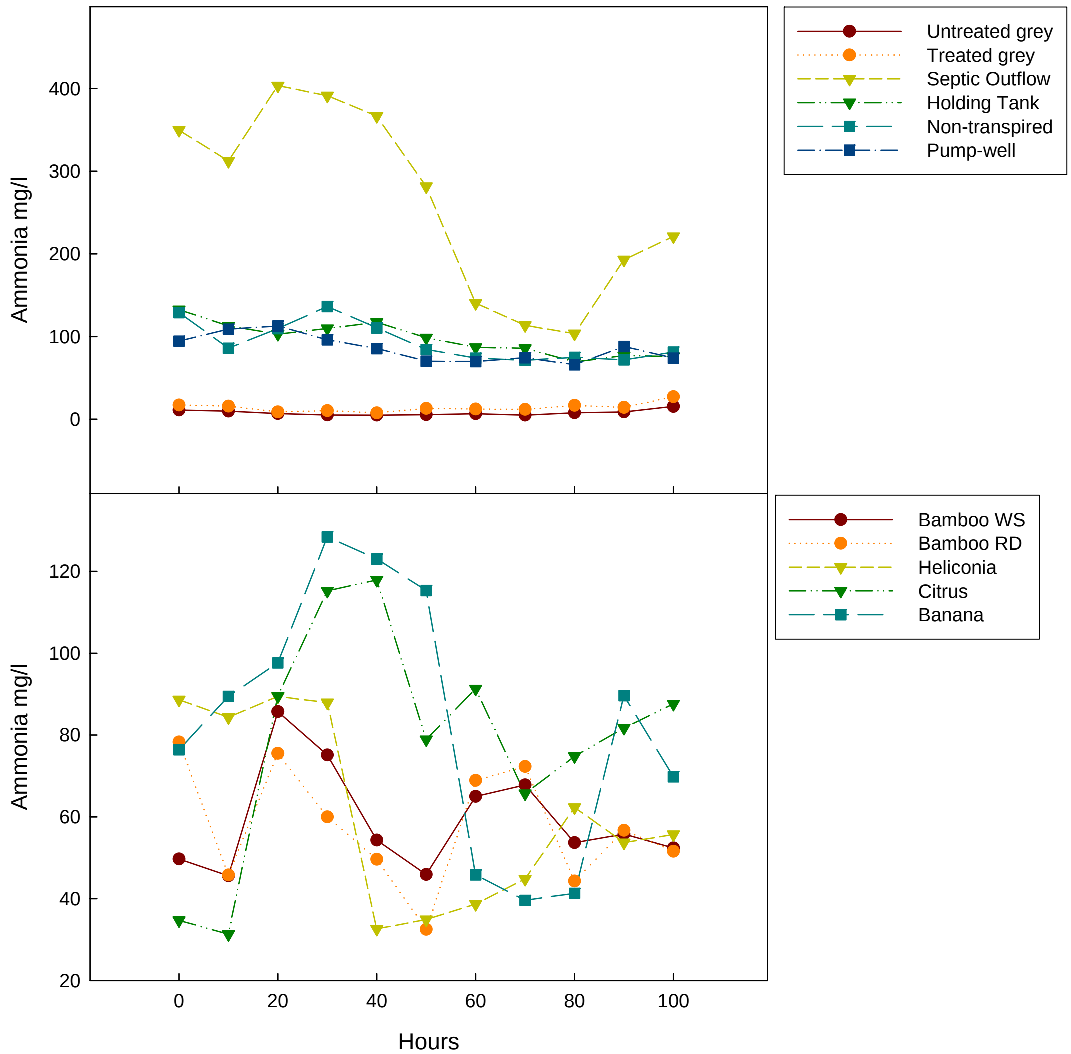


This indicated that different water quality conditions might have occurred in the two channel lengths. This could be caused by different effluent flow patterns through the aggregate layer that resulted in particular microenvironments. The formation of biofilms within the aggregate layer could have caused distinct microenvironments to occur, particularly in regards to oxygen concentrations. If flow of oxygenated effluent was restricted in a particular part of the aggregate layer this might have resulted in a microenvironment in which the microorganism species were distinctly different to other sections of the aggregate layer (Matos and Sousa 1991). Microenvironments are often formed in the rhizosphere (Elgala and Amberger 1988). The rhizosphere is the soil that immediately surrounds plant roots (Piceno and Lovell 2000). The soil in the rhizosphere is noticeably dissimilar to the soil in the remaining volume, often having different pH, oxygen conditions, nutrient concentration and diverse microorganisms (Elgala and Amberger 1988; Espeleta *et al.* 1999; Piceno and Lovell 2000; Salt *et al.* 1999). Physical examination of the pipework and aggregate layer showed no invasion by plant roots in these sections of the RET channels, however biofilm growths were observed. The clogging nature of these biofilms can change the environmental and biological conditions of their immediate environment (Avnimelech and Nevo 1964; Kawanishi *et al.* 1990; Kristiansen 1981; Vries 1972). While some nitrate ions may have leached from the soil in the RET channels into the effluent, it is thought that the main variation in nitrate ion concentration between the RET channels occurred due to different microbiological nitrogen oxidisation rates. The RET channels may have had different microbiological nitrogen oxidisation rates due to diverse effluent flow rates and microenvironments present within each channel. The nitrate ion concentrations did not remain constant in any of the RET channels. The microenvironments within the RET channels may have frequently changed due to differences in the effluent quality or environmental conditions. The heliconia channel had a higher average concentration of nitrate ions in December 2000. The citrus and banana channel lengths experienced marked increases in the concentration of nitrate ions in both 100 hour trials, but no increase lasted more than 25 hours. The elevated concentration of nitrate ions appeared to mostly remain in the RET channels and were not transferred in large quantities to the non-transpired effluent. The highest nitrate concentration of 18 mg/l was found in the banana RET channel in December 2000. The maximum value that the non-transpired effluent reached was 8 mg/l in December 1999, however this did occur when the heliconia and banana channel lengths were at relatively high concentrations.

3.1.2.3 Ammonia 100 Hour Nutrient Variation Study at Rockhampton site

The ammonia ion concentrations for the eleven sample points are reported in Figures 3.3 and 3.4. Ammonia ion concentrations were consistently low for untreated and treated greywater in both years. No marked inputs of ammonia through greywater occurred during the two 100 hour examination periods. The septic tank effluent had the highest concentration of ammonia ions. During both trials ammonia ions decreased markedly, in 1999 between 40 and 80 hours, and in 2000 between 10 and 50 hours. These decreases took effect over the weekend shutdown at the factory when no new inputs of wastewater occurred. With no new inputs of blackwater into the septic tank it appeared that the concentrations of ammonia ion in the septic discharge decreased. After work resumed at the factory and new inputs of wastewater were added the ammonia ion concentration in the septic discharge increased.

Figure 3.3 Ammonia ion concentrations in the Rockhampton RET system over 100 hours in December 1999

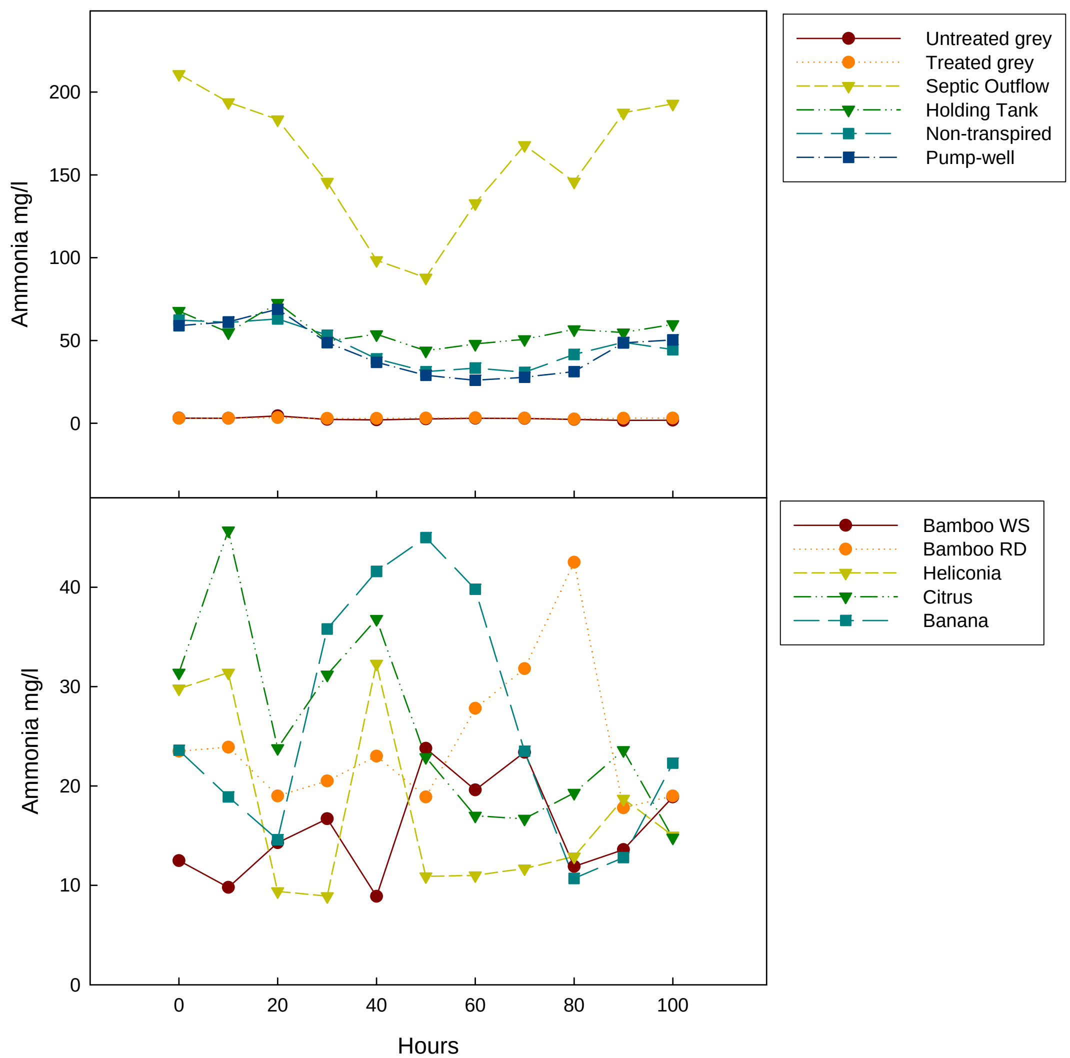


The ammonia ion concentrations in the septic discharge decreased dramatically between December 1999 and December 2000 (Figure 3.4). In December 2000 there was one less worker employed at the factory and two other employees had gone on annual leave. In effect this meant that three less people were generating wastewater at the factory. This may account for the lower concentration of ammonia ions in the septic discharge. The ammonia ion concentrations in the holding tank effluent, non-transpired effluent, and the pump-well decreased by approximately one-half in December 2000 compared to December 1999. Minimal variation occurred between the holding tank, non-transpired and pump-well effluent in respect to ammonia ion concentration.

A substantial reduction in the concentration of ammonia ions in the selected RET channels also happened between December 1999 and December 2000. However large amounts of variation in ammonia ions took place among the various channels and within each channel over the 100-hour examination periods. No clear impact of weekend shutdowns could be established from the RET channel data.

In 1999 the bamboo WS and bamboo RD ammonia ion concentration pattern showed a higher degree of similarity than what occurred with nitrate ions during the same period. In 2000 the bamboo WS and bamboo RD ammonia ion concentrations were notably dissimilar. The amount of variation in relation to ammonia ions within all of the selected RET channels indicated that microbiological oxidation of nitrogen had taken place. The holding tank and non-transpired effluent data did not show that ammonia ions had been transferred and accumulated in other parts of the RET system. On average the concentrations of ammonia ions within the RET channels was smaller than in the holding tank effluent.

Figure 3.4 Ammonia ion concentrations in the Rockhampton RET system over 100 hours in December 2000



The disparity in the ammonia ion concentrations between the RET channels and within the RET channels over time indicated that the rate of microbiological nitrogen oxidation was influenced by a variety of factors that were not constant within different parts of the RET system.

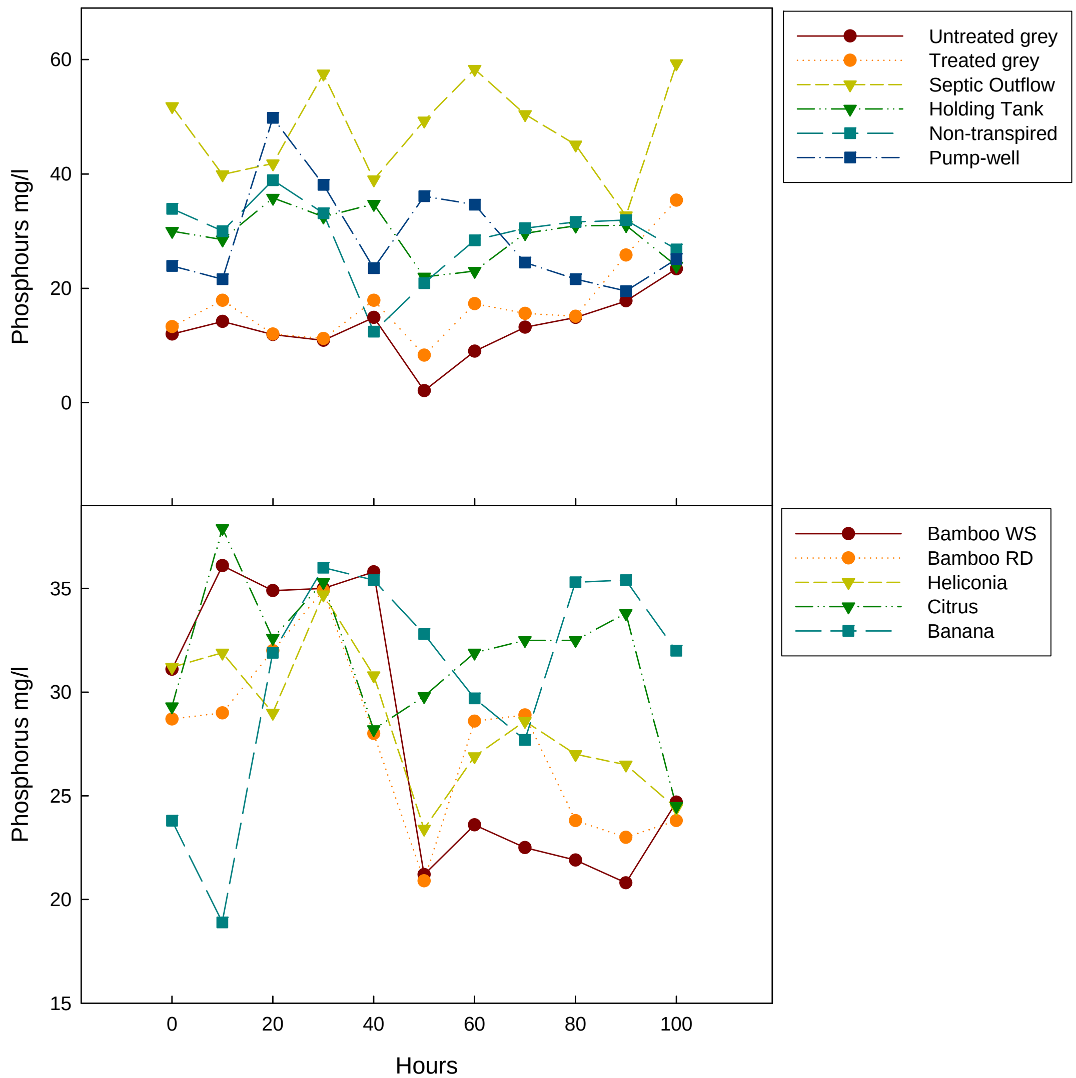
3.1.2.4 Phosphate 100 Hour Nutrient Variation Study at Rockhampton site

In Figures 3.5 and 3.6 the data for the Phosphate ion concentrations for the nutrient variation study are presented. The reduction in ion concentration that happened with ammonia ions between the 1999 and 2000 trials was not evident for phosphate. The major input source, leading to greatest concentration of ions recorded for both ammonia and phosphate was the septic tank discharge. If the quantity of ammonia ions fell in the December 2000 septic discharge due to smaller input volumes than why didn't phosphate ions follow the same pattern? Three possible reasons have been identified:

1. Phosphate ions had accumulated within the effluent because the plants were not using all of the phosphate available in the effluent
2. The volume of greywater was greater than the volume of blackwater entering the system (approximately 4:1). This could mean that the even though greywater had a smaller concentration of ions; its total input was higher due to a greater volume of input effluent
3. Phosphorus is excreted in the faeces as well as the urine. Ammonia is predominately excreted in the urine. If the quantity of faecal matter in the septic tank had not substantially decreased the amount of phosphate ions in the septic discharge may not have markedly reduced

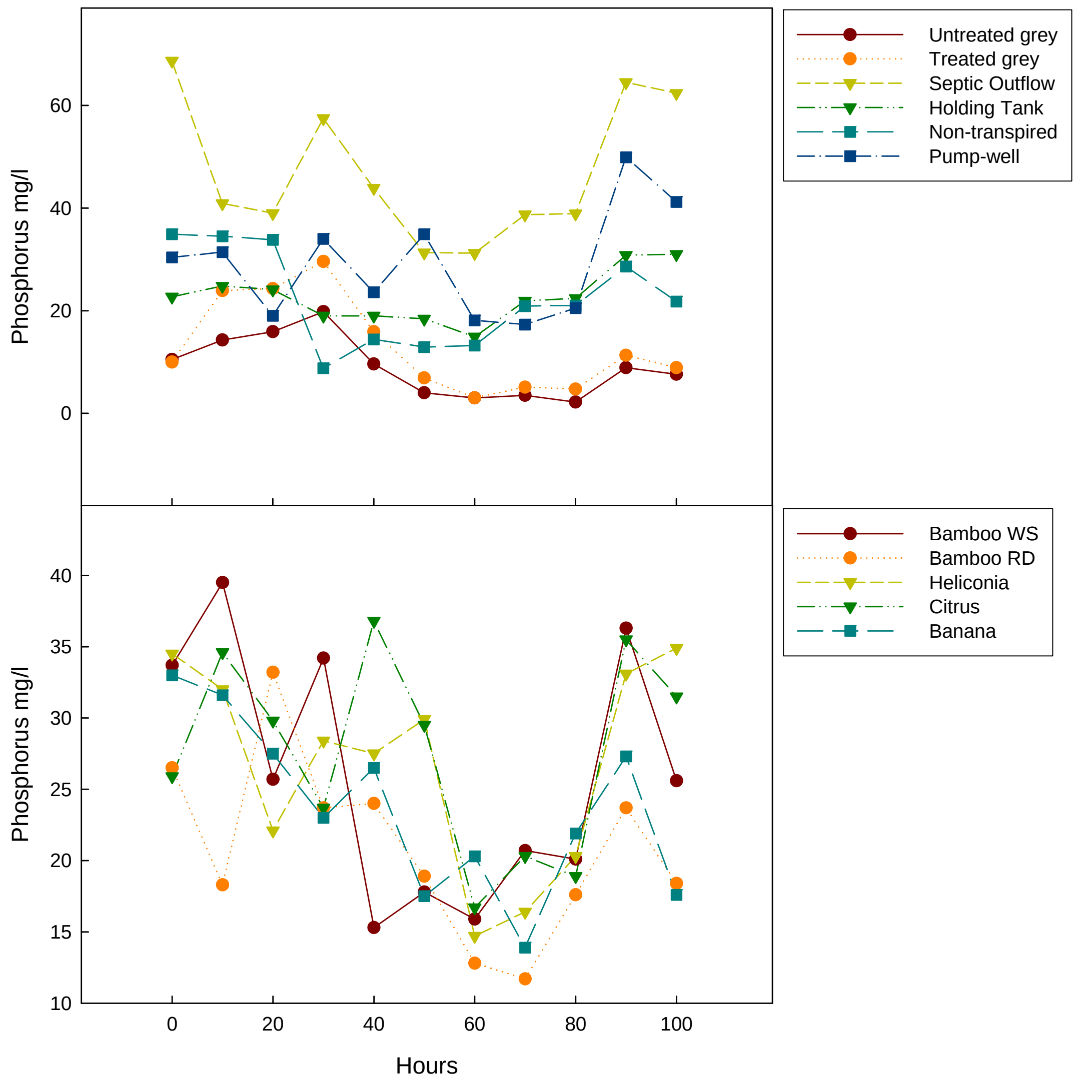
It was not possible to determine if all or any of these reasons impacted on the phosphate ion concentration between December 1999 and December 2000.

Figure 3.5 Phosphate ion concentrations in the Rockhampton RET system over 100 hours in December 1999



There was no marked difference in the phosphate ion concentrations in the untreated and treated greywater or septic discharge in the two trials. The phosphate ion concentrations for the holding tank, non-transpired, and pump-well effluent followed relatively similar patterns.

Figure 3.6 Phosphate ion concentrations in the Rockhampton RET system over 100 hours in December 2000



The pump-well effluent showed the most variation with a similar peak (20th hour 1999; 80th hour 2000) in each year. The cause of this peak was not known though it was mimicked to a small degree by the non-transpired effluent.

The transformation of phosphate through microorganisms in the external environment and the bioavailability of phosphorus in effluent irrigation reuse are not well understood (Datta and Aggarwal 1998; Haygarth and Sharpley 2000; Sharpley 1995; Wang and Park 1998). The literature does not appear to have reached a consensus on what processes are involved when phosphorus from wastewater is transformed by microorganisms and what impacts soil types have on the bioavailability of the phosphorus before and after it has been transformed (Bond *et al.* 1999; Falkiner and Polglase 1999; Menzies *et al.* 1999; Robertson *et al*. 1998; Rydin and Otabbong 1997). A simple explanation for the variations in the phosphate ion concentrations in the RET channels is not available.

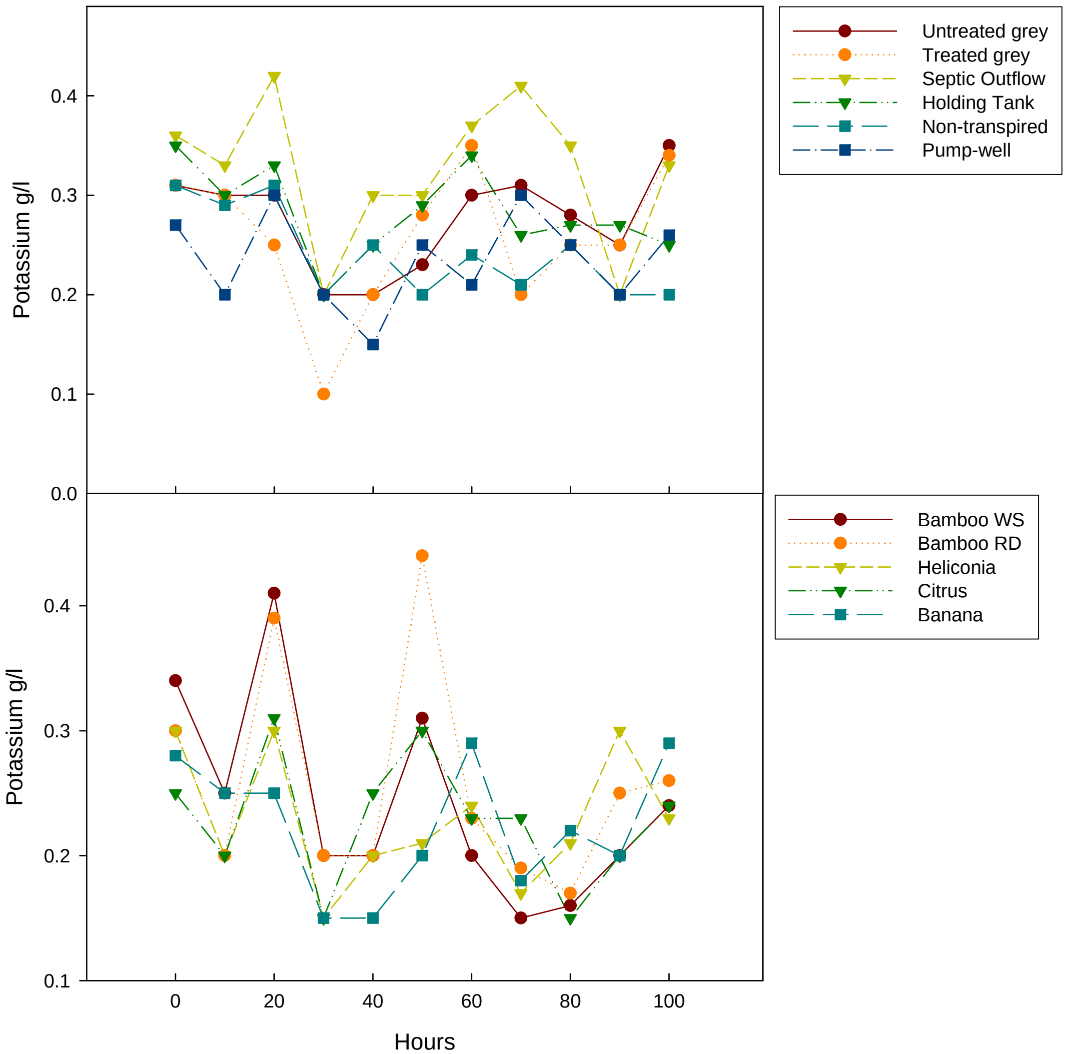
Bamboo WS and bamboo RD showed similar phosphate ion concentration patterns over the course of both 100 hour trials when compared to the large variations present for the nitrate and ammonia ions. The concentration of phosphate ions showed greater variation during December 2000 in the heliconia RET channel than it did for the same period in 1999. Phosphate ion concentrations were relatively high in the citrus RET channel in both years. The banana RET channel showed the largest degrees of variation in phosphate ion concentrations. In December 2000 all of the RET channel lengths showed a marked decrease in phosphate ion concentration between the 40th hour and the 80th hour. This was not during a shutdown period and the cause for this collective decrease is not known. The concentration of phosphate ions in the septic tank effluent did decrease slightly during this time; but the holding tank concentration did not.

3.1.2.5 Potassium 100 Hour Nutrient Variation Study at Rockhampton site

The potassium ion concentrations for the two 100-hour trials are reported in Figures 3.7 and 3.8. Potassium ion concentrations on average showed an overall small decrease between December 1999 (0.24 g/l) and December 2000 (0.21 g/l). No marked decreases in potassium ion concentrations happened during weekend shutdowns at the factory. In both years the potassium ion concentrations between the untreated and the treated greywater varied to a greater extent than what occurred with the other nutrients. The reason for this is unknown. The variation was not constant with untreated greywater on occasion having a greater concentration of potassium ions in relation to treated greywater and vice-versa. The average concentration of potassium ions in the septic discharge was slightly lower in December 2000 than it was in December 1999. The ratio of potassium ions between the holding tank, non-transpired, and pump-well effluent did not change markedly between years or during the 100-hour trials.

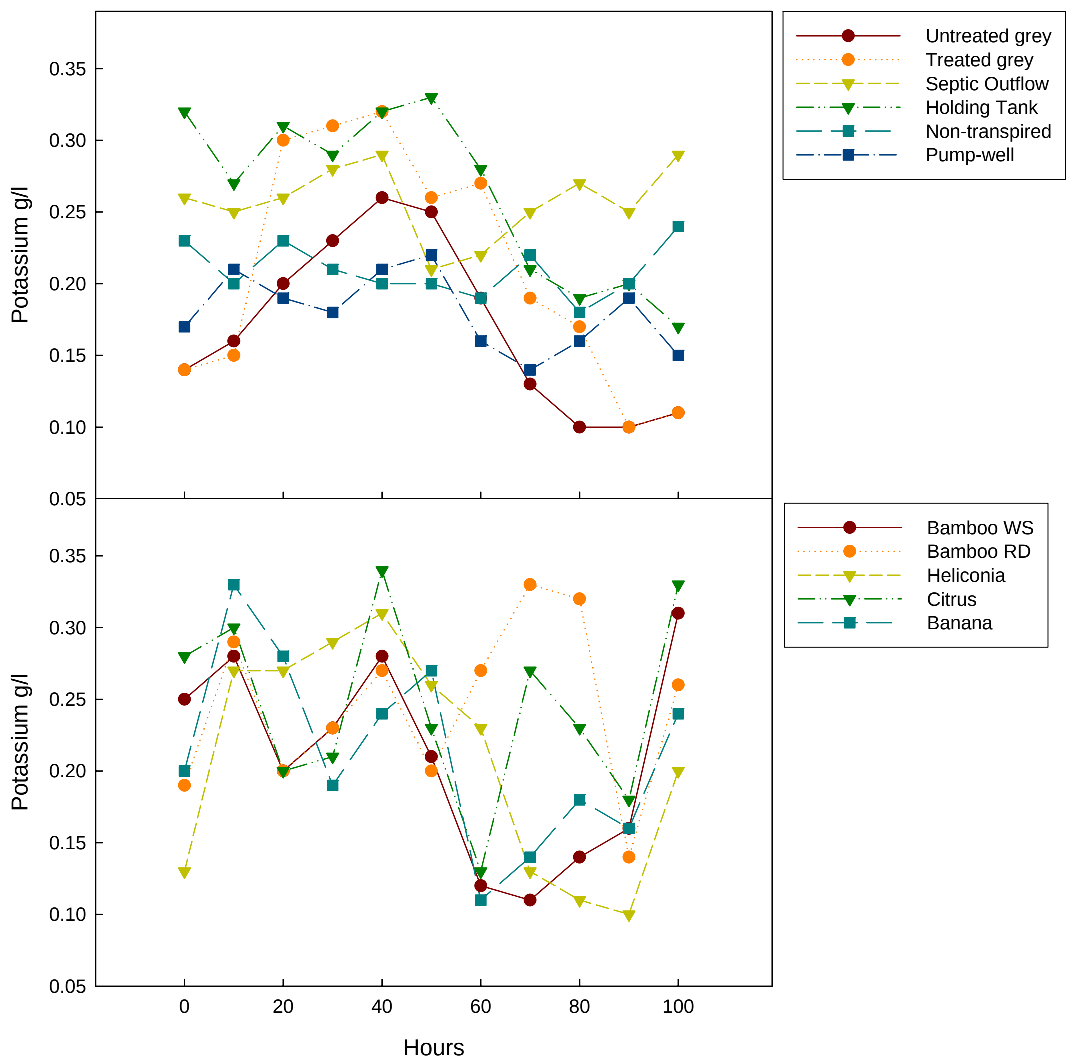
Bamboo WS and bamboo RD followed similar potassium ion concentration patterns in December 1999 and during the first 50 hours of December 2000. Between hours 50 and 90 in December 2000 potassium ions peaked in bamboo RD and decreased dramatically in bamboo RD. The cause of this was unknown, but, as mentioned earlier, it may have been due to different microenvironments within each respective RET channel length.

Figure 3.7 Potassium ion concentrations in the Rockhampton RET system over 100 hours in December 1999



In the heliconia channel the quantity of potassium was relatively constant in 1999; but fluctuated markedly in 2000. This also occurred in the citrus channel length. The concentration of potassium ions in the banana channel length was relatively small in both years (average: 0.23 g/l 1999; 0.21 g/L 2000).

Figure 3.8 Potassium ion concentrations in the Rockhampton RET system over 100 hours in December 2000



3.1.2.6 Discussion of 100 Hour Nutrient Variation Study at Rockhampton site

The aim of this experiment was to determine the variability of the nutrient ion concentrations entering, within, and recirculating through the RET channels at the Rockhampton site. This was important as it provided information as to how the RET system reacted to different levels of nutrients. In general the experiments showed that nutrient ions did not simply accumulate within the recirculated effluent. If this had been the case the nutrient ion concentrations would have risen as new inputs were added and no values would not have decreased at all. All of the nutrient ions levels fluctuated, possibly, in response to a variety of factors. It is thought that nutrients were:

- Microbiologically transformed
- Chemically transformed
- Immobilised in microbiological biofilms
- Adsorbed by the soil
- Utilised by the plants

The exact proportions of the nutrient ions that were used/transformed by each of the potential factors could not be determined. The variation within the RET channels suggested that these factors were not uniformly applied throughout the system. Specific localised environments within the RET channels appear to have formed. These could be influenced by hydraulic flow, oxygen concentration, and plant type.

It may have been useful to have flow data through the RET system for this experiment but this could not be achieved. The use of flow meters at the Rockhampton site was undertaken at the start of the trial. The flow meters proved unreliable due to the presence of solids in the primary treated effluent and the water recirculated from the RET system. The solids damaged the flow meters and that resulted in inaccurate results. The use of flow meters was stopped early in the trial. In a recirculating trial flow meters must be used with care, as it is impossible to determine how many times a particular volume of effluent has passed through the various treatment processes.

3.2 Microorganisms

There has been much debate over which microorganisms to use to assess water quality (Rose and Gerba 1991; Toze 1999). New molecular-based microbe identification techniques that specifically target human pathogens have been proposed to replace older plate count techniques that cannot quickly determine whether a microorganisms is a human or non-human pathogen (APHA 1999; Griffin *et al.* 2000; Sobsey *et al.* 1998; Turner *et al.* 1997). One of the major concerns is that many potential pathogens have non-anthropogenic sources, such as excrement produced by animals and insects. It is important to be able to establish in a water quality sample what microorganisms are produced from human wastewater and what microorganisms are produced from other biological sources.

Microorganisms produced from the waste of non-human life forms may or may not be harmful to humans. For example, all species of *Salmonella* produce disease in humans, whereas only a small percentage of *Escherichia coli* species have harmful effects in humans (Gopo and Chingobe 1995; Han *et al.* 2000; Ho and Tam 2000; Morinigo *et al.* 1990). The ability to be able to test a sample of water and determine exactly what and how many microorganisms are present, viable and able to cause disease in humans is a process that is still under development.

The aim of the microbiological water quality tests was to establish if potential pathogens were present and in what concentrations. The microbiological tests on water quality in the RET system were performed using the plate count methods. This was done as these techniques are still acknowledged as standard tests and because of the design of the RET system lent itself to this procedure. The closed nature of the technology, especially the plastic barrier covering the RET channels themselves limited the entry of non-human derived wastewater into the system, especially those from mammal and bird sources. It was assumed for the course of the trial that the majority of the effluent in the RET systems came from human related wastewater generation. A small amount of animal waste may have entered the treatment system through practices undertaken in the households; such washing a dog in a bath. It was not possible to control for the effects of these occurrences.

The majority of the tests undertaken focused on coliform counts. Coliforms are Gram-negative, non-spore forming rod bacteria that are able to ferment lactose with gas formation at 35°C within 48 hours (Csuros and Csuros 1999). Coliform bacteria are known to indicate the presence of human or animal excrement. The coliform bacteria most commonly tested for are *E.coli*, *Citrobacter*, *Enterobacter*, and *Klebsiella* (Csuros and Csuros 1999). The summation of the colony forming units of these four genera of coliforms gives what is known as a total coliform count. *E.coli*, *Citrobacter* and *Enterobacter*, are all found in the human and animal excrement, with *E.coli* usually being found in the largest concentrations (Csuros and Csuros 1999). *Klebsiella*, is also present in most excrement from warm-blooded animals, but needs relatively large quantities of carbohydrates to flourish. In industrial wastewater that contains carbohydrates in bulk, such as from paper mills or sugar cane factories, *Klebsiella* normally becomes the predominate coliform out-competing the other genera.

Microbiological tests were also performed to establish the concentrations of *Salmonella* species in the treated effluent. *Salmonella* is a gram negative, motile rod, facultative anaerobic bacteria that can ferment glucose to produce gas (Csuros and Csuros 1999). They are a common waterborne pathogen not necessarily associated with faecal contamination. These bacteria are responsible for a disease known as *salmonellosis*, the severity of which depends on the number of bacteria ingested (Csuros and Csuros 1999). Some tests for *Salmonella* species only give a positive or negative result in relation to presence of the bacteria. A test was chosen for this trial that gave an enumeration of the *Salmonella* colony forming units. *Salmonella* are able to survive and replicate at lower temperatures than most other bacteria that live in the intestinal tracts of animals (Morinigo *et al*. 1990).

The final group of microorganisms tested for were non-fastidious heterotrophic organisms. These organisms include aerobic and facultative anaerobic bacteria, moulds, and fungi (Csuros and Csuros 1999). The microorganisms present in this test may or may not be associated with the presence of wastewater and excrement (Csuros and Csuros 1999). Many non-fastidious heterotrophic organisms would be able to live in the various biofilms in the RET system. When non-fastidious heterotrophic organisms are present in concentrations greater than 500 colony forming units per ml they may suppress coliform growth (Csuros and Csuros 1999).

3.2.1 Materials and Methods

There were four microorganism water quality trials. The first involved a long-term study on the microorganisms in the holding tanks of the eight test sites. The second investigated the impact on the microorganisms present in the holding tank effluent when extended periods of no new inputs of wastewater occurred. The third trial examined the AWTS before and after the RET treatment system was installed at St Lawrence recreation area. The last trial compared the various treatment stages of the Gem-Air caravan park.

In the long-term holding tank trial two effluent samples were taken from each tank, 100 ml from the top of the holding tank and 100 ml from 500 mm from the bottom of the holding tank. The two samples were combined into one composite sample with a volume of 200 mL. This technique should have resulted in the most representative sample (Haas 1993; Tillett 1993). The samples were stored at a temperature of 4°C and transported to the microbiological laboratory of CQU and analysed within 24 hours. The different types of effluent samples were analysed by the Chromocult^{tm} and non-fastidious heterotrophic pour plate techniques. A 10^{-6}

dilution series was carried out for the samples. The non-fastidious heterotrophic pour plate technique described in Csuros and Csuros (1999) was used.

The pour-plate method for the faecal coliform selective media Chromocult^{tm} described in Frampton *et al*. (1988) and Manafi and Kneifel (1989) was performed. The petrifilm^{tm} and heterotrophic pour plates were incubated at 28°C for 48 hours. The Chromocult^{tm} pour plates were incubated at 37°C for a 24-hour period. The Chromocult^{tm} media was selected because each plate can give a count for *E.coli* (purple colonies), *Enterobacter, Citrobacter,* and *Klebsiella* species (blue colonies), *Salmonella* species (red-pink colonies), and non-enteric bacteria (white colonies).

The non-enteric bacteria are organisms able to grow on the Chromocult^{tm} media but which are not faecal coliforms. The Chromocult^{tm} media provided a range of faecal coliform counts for a relatively low-cost in time and laboratory reagents. Both types of plate counts involved two plates being poured for each sample and the result being an average of the two counts. The tests were performed on samples collected twice per year; the results are presented as an average of the two readings. The samples were collected in late April and mid-August.

At the Rockhampton trial site the business went through periodic shutdowns at Easter and Show-week in June. These events had public holidays associated with them in conjunction with weekends. At Easter the business shut on the Thursday before Good Friday and did not open until the Tuesday after Easter Monday. During

Show-week the business shut on Wednesday before the show public holiday and did not resume trading until the following Monday. This meant for both shutdowns there were no new inputs of wastewater for four days. Samples were collected from the holding tank of the Rockhampton site at 11:00 am on the last day of trading before shut down. These samples were stored, transported, and analysed according to the methods and materials previously described for the long-term holding tank microorganism study. The results of these samples were used as the before shutdown data. At 6:30 am on the day that business resumed at the site samples were taken from the holding tank. These samples underwent analysis and were used to describe the after shutdown results. This trial was conducted during Easter 2001, 2002 and Show-week 2001, 2002.

While no new wastewater was added during the four-day shutdown the low-water feed did add some water to the system. The low-water feed at the Rockhampton site was connected to the Rockhampton potable water supply. It was not possible to correct for any microorganisms added to the RET holding tank from this water source or to evaluate any impact residual chlorine in the potable water supply had on the results. The aim of the trial was to establish whether potential pathogen colony forming units decreased in the recirculatory system when no new inputs of wastewater were added.

The Broadsound Shire Council was interested in determining the treatment performance of the ATWS installation at St Lawrence recreation area before and after the RET system was installed. Composite samples (200 ml) were taken from the septic tank and disinfection chamber of the AWTS system five months prior to the installation of the RET system. Three composite samples from each treatment system were taken. These samples were stored and transported at 4°C and were driven to Queensland Health Scientific Services on Kessels Rd Brisbane for analysis. The samples arrived approximately 12 hours after they were taken. They were assessed for *E.coli*, total coliforms, *Salmonella* species, and non-fastidious heterotrophic organisms. The methods described in APHA (1999) were used. Results from the three samples were reported as an average. Five months after the RET system was installed the test was repeated; however additional samples were taken from the holding tank, and the RET channel. The holding tank composite sample was taken using the methods previously described.

The RET channel sample was obtained from a sample point at the start of the non-transpired effluent return line. This meant that the sample was possibly a mixture of effluent from all four RET channel runs. Three 200 ml samples were taken from this test point. The samples were stored and transported to Queensland Health Scientific Services in Brisbane at 4°C. The samples arrived at the test facilities just over 12 hours after collection. The same analytical tests performed on the previous samples were conducted, with the results reported as an average. The aim of the tests was to establish whether the installation of the RET system had a positive or negative impact on the colony forming units of potential pathogens in the primary treatment tank and the AWTS.

At the Gem-Air site there are several different types of effluent treatment; these are septic tanks, RET channels, a recirculating sand and zeolite filter, and chlorine disinfection. This is the first time that these particular types of treatment have been used together. To determine how effective the treatment systems were at reducing potential pathogens a series of microbiological tests was conducted sequentially through the treatment stages. These tests were performed using the methods previously described in the long-term holding tank study. The experiment was conducted four times, twice during the tourist season of 2002 and twice during the tourist season of 2003. Tests were not conducted outside the tourist season as the prolonged absence of new inputs of wastewater may have given misleading results if used to state system performance.

3.2.2 Rockhampton site

The colony forming units (cfu) of the microorganisms in the holding tank of the Rockhampton site are reported in Table 3.10. *Salmonella* was present in all tests with the highest cfu occurring in 2002. For effluent kept at least 400 mm below ground level the cfu for *Salmonella* was not considered to be at non-compliance concentrations for this type of treatment and reuse system (Goonetilleke *et al*. 1999; Gopo and Chingobe 1995; WS/13/1 2000).

Table 3.10 Microorganisms in holding tank at Rockhampton site

Test	2000	2001	2002	2003
Salmonella species (cfu/100 mL)	4.35×10^{3}	8.57×10^{2}	6.07×10^{4}	5.09×10^{3}
E.coli (cfu/100 mL)	6.6×10^{3}	7.45×10^{6}	3.03×10^{2}	3.12×10^{4}
CEK[1] species (cfu/100 mL)	3.27×10^{5}	7.06×10^{4}	8.23×10^{4}	1.49×10^{3}
Non-enteric bacteria (cfu/100 mL)	4.53×10^{4}	8.23×10^{4}	2.03×10^{5}	2.64×10^{4}
NFH[2] (cfu/1 mL)	8.32×10^{6}	9.36×10^{7}	1.05×10^{5}	1.31×10^{6}

CEK[1] - *Citrobacter*, *Enterobacter*, and *Klebsiella*

NFH[2] - Non-fastidious heterotrophic

E.coli cfu counts were at least two-logs greater in 2001 than they were in any other year. The cause for this was unknown but may have been due to a relatively high ratio of primary treated effluent to recycled excess effluent in the holding tank. The Rockhampton holding tank had the smallest volume and may have been susceptible to shock loads from the primary treatment tanks. No test results for *E.coli* colonies were not at non-compliance levels. The counts for CEK were relatively high when compared to the *E.coli* counts; normally *E.coli* is the main faecal coliform in wastewater samples (Csuros and Csuros 1999). This site did have some industrial wastewater but the amount of carbohydrates in the wastewater was not determined. The non-enteric bacteria and the NFH organisms were present in high numbers and may have caused some suppression of coliform numbers.

In Tables 3.11 and 3.12 data from the shutdown water treatment trials for the Easter and Show-week public holidays are presented. The most dramatic decrease occurred in the number of cfu for *E.coli*. In all cases during shutdown log reductions of *E.coli* occurred that resulted in an average of <1 cfu per 100ml of effluent in the holding tank. This type of log-reduction did not occur with the other faecal coliforms (CEK), although a one-log reduction for CEK did happen in both show-holiday long weekend trials. *Salmonella* species had at least a one log increase during the shutdown period in all trials. It is thought that *Salmonella* species were able to increase because the environmental temperatures may have been more suitable for its replication and the absence of new inputs of wastewater reduced the competition from additional coliform bacteria.

Table 3.11 Microorganisms in holding tank before and after the Easter public holidays at the Rockhampton site

Test	Before Easter 2001	After Easter 2001	Before Easter 2002	After Easter 2002
Salmonella species (cfu/100 mL)	7.0×10^4	1.4×10^5	3.2×10^2	5.53×10^5
E.coli (cfu/100 mL)	1.5×10^3	<1	6.98×10^4	<1
CEK[1] species (cfu/100 mL)	1.5×10^3	3.5×10^3	2.71×10^3	1.03×10^2
Non-enteric bacteria (cfu/100 mL)	3.99×10^2	1.78×10^2	1.56×10^2	2.5×10^2
NFH[2] (cfu/1 mL)	1.05×10^5	3.9×10^4	4.5×10^5	4.01×10^5

CEK[1] - *Citrobacter*, *Enterobacter*, and *Klebsiella*

NFH[2] - Non-fastidious heterotrophic

The system appears to treat thermotolerant coliforms well but is less effective with other potential pathogens.

The non-enteric bacteria and the NFH organisms remained at relatively constant counts in both years and did not seem to be adversely or positively influenced by the factory shutdown.

Table 3.12 Microorganisms in the holding tank before and after the show holiday long weekend at the Rockhampton site

Test	Before Show-holiday long weekend 2001	After Show-holiday long weekend 2001	Before Show-holiday long weekend 2002	After Show-holiday long weekend 2002
Salmonella species (cfu/100 mL)	3.64×10^3	4.06×10^4	7.05×10^3	5.87×10^4
E.coli (cfu/100 mL)	5.23×10^4	<1	3.08×10^3	<1
CEK[1] species (cfu/100 mL)	9.83×10^4	4.25×10^3	6.4×10^3	3.62×10^2
Non-enteric bacteria (cfu/100 mL)	5.69×10^2	4.36×10^2	8.08×10^3	2.6×10^3
NFH[2] (cfu/1 mL)	2.3×10^6	1.78×10^6	7.67×10^7	8.06×10^6

CEK[1] - *Citrobacter*, *Enterobacter*, and *Klebsiella*

NFH[2] - Non-fastidious heterotrophic organisms

3.2.3 St Lawrence domestic site

The cfu counts for the selected microorganisms present in the holding tank of the St Lawrence domestic site are presented in Table 3.13. The *Salmonella* species cfu counts peaked in 2001 but were present at substantially reduced numbers in other years. Conditions may have been more suited for *Salmonella* species within the RET system in 2001 or input quantities could have been much greater.

The cfu counts for *E.coli* were consistent with no marked increases or decreases. The amount of CEK colonies reflected the standard range of *E.coli* to CEK counts for domestic wastewater (Csuros and Csuros 1999). Non-enteric bacteria counts were steady whereas NFH counts peaked in 2002 with cfu's two-logs greater than first tally taken in 2000.

Table 3.13 Microorganisms in the holding tank at the St Lawrence domestic site

Test	2000	2001	2002	2003
Salmonella species (cfu/100 mL)	2.35×10^{2}	7.23×10^{5}	4.03×10^{2}	1.03×10^{3}
E.coli (cfu/100 mL)	4.35×10^{5}	7.89×10^{4}	1.24×10^{5}	1.78×10^{4}
CEK[1] species (cfu/100 mL)	5.69×10^{2}	5.47×10^{3}	9.09×10^{2}	9.83×10^{2}
Non-enteric bacteria (cfu/100 mL)	4.48×10^{5}	3.02×10^{4}	7.08×10^{4}	6.9×10^{4}
NFH[2] (cfu/1 mL)	5.62×10^{7}	4.89×10^{8}	5.37×10^{9}	8.29×10^{8}

CEK[1] - *Citrobacter, Enterobacter*, and *Klebsiella*

NFH[2] - Non-fastidious heterotrophic organisms

3.2.4 St Lawrence Recreation Area

The results for the three-examination of the selected microorganisms in the holding tank at the St Lawrence recreation area are shown in Table 3.14. The counts of Salmonella cfu's were stable but the species was present in large quantities. The wastewater inputs to this site occurred through showers, toilets, hand-basins, and a washing machine, no commercial kitchen waste, which can often be a source of *Salmonella* species, was present (Csuros and Csuros 1999). The conditions at the site, conceivably within the 11 000 L septic tank, may be suitable for the growth of *Salmonella species*.

Table 3.14 Microorganisms in the holding tank at the St Lawrence recreation area

Test	2001	2002	2003
Salmonella species (cfu/100 mL)	8.86×10^6	8.05×10^6	1.19×10^7
E.coli (cfu/100 mL)	1.98×10^3	2.56×10^3	7.05×10^3
CEK[1] species (cfu/100 mL)	7.63×10^2	6.08×10^2	2.15×10^3
Non-enteric bacteria (cfu/100 mL)	5.27×10^5	7.55×10^4	4.38×10^5
NFH[2] (cfu/1 mL	4.56×10^8	6.64×10^7	7.11×10^7

CEK[1] - *Citrobacter, Enterobacter*, and *Klebsiella*

NFH[2] - Non-fastidious heterotrophic organisms

Both coliform counts; *E.coli* and CEK were consistent over the three years with no marked deviations. The ratio of CEK to *E.coli* was at the top range for domestic wastewater. Non-enteric bacteria colonies were present in substantial quantities;

conditions must have supported their growth. The counts of NFH cfu's were constant.

The microbial quality of the effluent was tested before the RET system was retrofitted at the St Lawrence recreation area and after. The septic tank and AWTS were the original treatment system at the area. Table 3.15 show the data from the septic tank, the disinfection chamber of the AWTS, the RET holding tank, and effluent sample taken from a RET channel.

Table 3.15 Treatment comparison before and after the RET system was installed at the St Lawrence recreation area site

Sample	NFH[1] per 1 ml at 28^{o}C/48 hrs	E.coli per 100 ml at 37^{o}C/48 hrs	Total coliforms per 100 ml at 37^{o}C/48 hrs	*Salmonella* spp. per 100 ml at 37^{o}C/48 hrs
Septic before RET retrofit	3.9×10^{7}	3.27×10^{5}	4.62×10^{6}	3.91×10^{6}
AWTS before RET retrofit	3.23×10^{7}	9.95×10^{5}	2 08 x 10^{6}	3.64×10^{6}
Septic after RET retrofit	2.9×10^{7}	1.27×10^{4}	9.84×10^{5}	1.54×10^{6}
AWTS after RET retrofit	1.0×10^{4}	70	4.2×10^{2}	1.89×10^{4}
RET Holding Tank	1.26×10^{6}	1.61×10^{5}	2.26×10^{5}	1.41×10^{5}
RET Channel	1.91×10^{6}	1.5×10^{2}	9.85×10^{3}	3.45×10^{4}

NFH[1] - Non-fastidious heterotrophic organisms

The installation of the RET system increased the detention capacity of the wastewater treatment and effluent reuse system by approximately 16 KL. This doubled the existing capacity of the system and minimised the impact caused by hydraulic surges at the site. The data in Table 3.15 clearly show an improvement in the performance of the septic tank and the AWTS after the RET retrofit. It is thought that *Salmonella* species numbers do not decline as significantly as *E.coli*, and total coliform numbers because they are more thermotolerant and can survive more readily at the lower water temperatures within the treatment and reuse systems.

3.2.5 Gem Air Caravan Park

In Table 3.16 the data for the selected microorganisms for the tests conducted on the holding tank at the Gem-Air caravan park are presented. The microbiological tests at this site were always conducted during the tourist season. The *Salmonella* and coliform counts for holding tank effluent were regular over the three years of the study. The 4500 L buffer tank before the holding tank may have resulted in a stable quality of in-flow effluent.

Table 3.16 Microorganisms in the holding tank at the Gem-Air caravan park

Test	2002	2003	2004
Salmonella species (cfu/100 mL)	2.03×10^4	4.12×10^4	9.61×10^4
E.coli (cfu/100 mL)	4.53×10^2	6.03×10^2	7.81×10^2
CEK[1] species (cfu/100 mL)	3.64×10^2	3.09×10^2	4.44×10^2
Non-enteric bacteria (cfu/100 mL)	7.35×10^5	5.05×10^6	5.5×10^6
NFH[2] (cfu/1 mL)	3.56×10^5	7.9×10^5	4.2×10^5

CEK[1] - *Citrobacter*, *Enterobacter*, and *Klebsiella*

NFH[2] - Non-fastidious heterotrophic organisms

The non-enteric bacteria and NFH organisms colony numbers were relatively stable over the three years. The non-enteric bacteria did occur at elevated quantities.

The data in Table 3.17 show the faecal coliform, non-enteric bacteria, and non-fastidious heterotrophic counts for the effluent after it has passed though each particular type of treatment.

Table 3.17 Range of colony forming units for the different treatment stages at Gem-Air caravan park in 2003

Test	Buffer Tank	Holding Tank	RET Trenches	Zeolite Filter	Reuse Tank
Salmonella species (cfu/100 mL)	Max: 3.5×10^5 Min: 2.25×10^4	Max: 2.5×10^5 Min: 7.0×10^4	Max: 8.5×10^5 Min: 3.0×10^4	Max: 4.85×10^5 Min: 2.0×10^5	Max: <1 Min: <1
E.coli (cfu/100 mL)	Max: 1.5×10^4 Min: 5.0×10^3	Max: 1.0×10^3 Min: <1	Max: 1.5×10^2 Min: <1	Max: 4.0×10^2 Min: 2.0×10^2	Max: 1 Min: <1
CEK[1] species (cfu/100 mL)	Max: 5.5×10^3 Min: 2.5×10^3	Max: 4.5×10^2 Min: <1	Max: 1.5×10^5 Min: <1	Max: 2.0×10^2 Min: 1.0×10^2	Max: 3 Min: <1
Non-enteric bacteria (cfu/100 mL)	Max: 2.81×10^6 Min: 2.65×10^6	Max: 2.81×10^6 Min: 1.65×10^5	Max: 2.4×10^5 Min: 1.3×10^5	Max: 8.5×10^5 Min: 6.4×10^5	Max: 1.625×10^6 Min: 1.03×10^5
NFH[2] (cfu/1 mL)	Max: 1.05×10^7 Min: 2.26×10^5	Max: 1.0×10^6 Min: 2.21×10^5	Max: 8.0×10^4 Min: 1.0×10^4	Max: 2.3×10^4 Min: 1.35×10^4	Max: 1.25×10^3 Min: 1.88×10^2

CEK[1] - *Citrobacter*, *Enterobacter*, and *Klebsiella*

NFH[2] - Non-fastidious heterotrophic organisms

The results presented in Table 3.17 show that the buffer tank produced a log reduction in the numbers of faecal coliforms entering the holding tank of the RET system. The RET system trenches showed high levels of *E.coli* reduction, but some increases in *Salmonella*, and CEK species. This may be because *Salmonella* and the other coliform species have a greater ability to survive and reproduce in the external environment than *E.coli* (Csuros and Csuros 1999). The sand and zeolite filter did not produce substantial reductions in cfu counts. In some instances the faecal coliform numbers increased after the effluent had passed through the sand and zeolite filter.

The temperature of the effluent in the sand and zeolite was higher than that of the effluent in the RET system trenches. The recorded temperature range of the effluent in the sand and zeolite filter was between 18.1°C and 26.9°C. The recorded temperature range of the effluent in the RET system trenches was between 14.8°C and 21.3°C. The effluent temperature was higher in the sand and zeolite filter because the media was not shaded; it was exposed to direct sunlight. The higher temperatures in the sand and zeolite filter may have provided an environment more suitable for the replication of those faecal coliform species that increased (Blanc and Nasser 1996; Thomas and O'Beirne 2000). The disinfection process with bromine-chlorine produced very low numbers of faecal coliforms and *Salmonella* species. It did not, however, produce sterile effluent as quantities ranging from the hundreds to the thousands per 1/ml of non-enteric bacteria and non-fastidious heterotrophic organisms were present. Probably due to the presence of soil organisms.

3.2.6 Sapphire site

The results from the microbiological tests performed on the Sapphire site holding tank over four years are presented in Table 3.18. The *Salmonella* species colony count for this site was low. It is likely that the *Salmonella* species were sensitive to the anti-microbial chemicals input through the chemical toilet dump at this site. Other environmental conditions, such as salinity, may have impacted on the ability of *Salmonella* species to replicate.

Table 3.18 Microorganisms in the holding tank at the Sapphire site

Test	2000	2001	2002	2003
Salmonella species (cfu/100 mL)	32	8.5	6	17
E.coli (cfu/100 mL)	2.03×10^2	1.56×10^2	2.8×10^2	98
CEK[1] species (cfu/100 mL)	3.12×10^2	42	78	81
Non-enteric bacteria (cfu/100 mL)	1.56×10^3	5.63×10^2	7.8×10^2	4.06×10^2
NFH[2] (cfu/1 mL)	5.98×10^4	5.63×10^5	7.02×10^4	4.36×10^4

CEK[1] - *Citrobacter*, *Enterobacter*, and *Klebsiella*

NFH[2] - Non-fastidious heterotrophic organisms

In 2003 the *E.coli* colony counts markedly declined after maintaining relatively constant numbers in previous years. The CEK counts substantially declined after just one year and remained at low numbers. It appeared that the conditions in the effluent were not conducive for the support of coliform growth in the long-term.

Non-enteric bacteria and NFH organisms remained at relatively constant quantities. These plate counts are not species specific, the actual genera and specific species of microorganisms counted in each year may have varied widely, while the colony forming units in the effluent remained stable. The type of bacteria and other microorganisms present in the effluent may have changed to suit new environmental conditions while the number of colony forming units remained practically unchanged.

3.2.7 Rubyvale site

The cfu counts for the microorganisms present in the Rubyvale holding tank are showed in Table 3.19. *Salmonella* species colony numbers remained at a constant log value over the four years, but changed markedly within that range.

Table 3.19 Microorganisms in the holding tank at the Rubyvale site

Test	2000	2001	2002	2003
Salmonella species (cfu/100 mL)	1.89×10^2	8.56×10^2	3.68×10^2	7.86×10^2
E.coli (cfu/100 mL)	6.98×10^5	1.75×10^6	7.28×10^5	8.37×10^6
CEK[1] species (cfu/100 mL)	3.04×10^3	4.49×10^3	2.6×10^2	8.31×10^3
Non-enteric bacteria (cfu/100 mL)	5.05×10^2	5.46×10^2	4.36×10^2	8.01×10^2
NFH[2] (cfu/1 mL)	8.53×10^2	2.4×10^2	7.61×10^3	7.06×10^4

CEK[1] - *Citrobacter, Enterobacter,* and *Klebsiella*

NFH[2] - Non-fastidious heterotrophic organisms

The counts of *E.coli* had a log increase in 2001 and 2003. The numbers of CEK species were steady and the ratio of CEK coliforms to *E.coli* colonies were within the range for normal domestic wastewater (Csuros and Csuros 1999). The counts of non-enteric bacteria and NFH organisms were similar in the first two years, after which the cfu's of the NFH rose by one-log per year.

3.2.8 Anakie site

In Table 3.20 the data for the microorganism colonies formed from the tests conducted on the Anakie holding tank are presented.

Table 3.20 Microorganisms in the holding tank at the Anakie site

Test	2000	2001	2002	2003
Salmonella species (cfu/100 mL)	3.06×10^{2}	2.56×10^{4}	4.5×10^{2}	7.23×10^{3}
E.coli (cfu/100 mL)	37	1.26×10^{2}	89	2.5
CEK[1] species (cfu/100 mL)	4.8×10^{2}	4.5×10^{2}	7.8×10^{2}	2.3×10^{2}
Non-enteric bacteria (cfu/100 mL)	8.36×10^{3}	7.52×10^{3}	8.06×10^{2}	4.12×10^{2}
NFH[2] (cfu/1 mL)	9.78×10^{5}	5.36×10^{6}	7.45×10^{6}	8.03×10^{7}

CEK[1] - *Citrobacter, Enterobacter*, and *Klebsiella*

NFH[2] - Non-fastidious heterotrophic organisms

The *Salmonella* species colonies showed some variation with a different log-count in each year. This site treated only greywater; it is thought that the majority of

Salmonella species entered through kitchen wastewater, although small quantities could be input through shower, hand-basin, and laundry wastewater. It is possible that *Salmonella* species replicated within the RET system and that the numbers of colonies within the holding tank effluent were not representative of the colonies numbers input through the greywater. *E.coli* were relatively low, as expected in greywater (Rose *et al.* 1991). The CEK coliforms were at slightly elevated levels for greywater; the cause for this was unknown. Non-enteric bacteria colony numbers slowly decreased over time, while NFH organism numbers slowly increased.

3.2.9 Yaamba site

The microorganism data for Yaamba are presented in Table 3.21.

Table 3.21 Microorganisms in the holding tank at the Yaamba site

Test	2000	2001	2002	2003
Salmonella species (cfu/100 mL)	3.68×10^3	4.78×10^4	5.62×10^4	4.9×10^4
E.coli (cfu/100 mL)	5.84×10^4	4.76×10^3	9.06×10^3	2.31×10^4
CEK[1] species (cfu/100 mL)	6.03×10^2	7.08×10^2	7.6×10^3	4.52×10^2
Non-enteric bacteria (cfu/100 mL)	4.5×10^2	7.23×10^2	4.62×10^3	6.03×10^2
NFH[2] (cfu/1 mL)	7.42×10^5	1.56×10^5	1.03×10^5	2.3×10^5

CEK[1] - *Citrobacter*, *Enterobacter*, and *Klebsiella*

NFH[2] - Non-fastidious heterotrophic organisms

The colony numbers of the coliform bacteria (*E.coli* and CEK) were constant with no striking deviations. The ratio between E.coli and CEK was maintained at the range normally associated with domestic wastewater (Csuros and Csuros 1999). There was no marked variation in the numbers of cfu's in the non-enteric bacteria. The NFH organism counts peaked in 2000 and then decreased slightly and were relatively stable over the next three years.

3.2.10 Discussion on Microorganism Water Quality

Except at the Gem-Air Caravan Park all of the treated effluent at the research sites was used for sub-surface irrigation of plants. The aim of the RET systems at these seven sites was not to eliminate microorganisms as this was not required by legislation, or needed to protect public or environmental health. The experiments conducted at the Rockhampton site during the shut-down periods showed that with no new inputs of wastewater the RET systems could dramatically decrease the numbers of cfu's of certain potential pathogens; such as *E.coli*.

These experiments also showed that other pathogens such as *Salmonella* sp. increased in these circumstances. *Salmonella* sp. are not regularly tested in on-site wastewater treatment technologies. An examination from the AWTS data at the St Lawrence recreation area, and the sand filter at the Gem-Air Caravan Park showed that *Salmonella* sp. were present in relatively high numbers in these treatment technologies. As all species of *Salmonella* are pathogenic to humans it might be beneficial to include the testing of this species in all areas were recycled water is used aboveground and can come into contact with people. The CEK study showed that these organisms did not follow the predicted theoretical cfu pattern that the type of wastewater and number of cfu's of *E.coli* suggested. This may be due to the fact that the predicted CEK ratio was obtained from studies conducted on wastewater at STP's rather than that gathered from on-site treatment systems.

Additional research into CEK in on-site wastewater would be useful. The NFH organisms survived well at the sites. This was important, as these organisms are needed for soil and plant health, as well as for the transformation of various nutrients. The Gem-Air Caravan site showed that the RET system in combination with other technologies could produce recycled water that was microbiologically safe for aboveground reuse. The results from within the different treatment technologies did highlight how certain species could increase numbers at different treatment stages if conditions for growth became favourable. Testing regimes for the recycled water should be robust enough to ensure potential pathogen populations are monitored and that increases in numbers are readily detected.

3.3 Salinity, pH, Dissolved Oxygen and Temperature

The adverse effects on the physical structure of the soil and the phytotoxic impacts on plants makes the accumulation of salts one the greatest limiting factors in the reuse of effluent (Bond 1998; Gordon and Gardner 1996; Graaff and Patterson 2001). Salts are present in wastewater in varying concentrations; but normally at quantities higher than found in reticulated town-water, freshwater waterways, and harvested stormwater commonly used for agricultural irrigation (Bond 1998; Tchobanoglous and Burton 1991). The water quality trials measured salinity as electrical conductivity (EC) and total dissolved solids/salts (TDS) (Tchobanoglous and Burton 1991). The relationship between EC and TDS can be described as:

TDS (mg/L) ≈ EC (dS/m) x 640.

In most situations this conversion is accurate to within about 10% (Tchobanoglous and Burton 1991). Quite often a measurement device will measure EC and use the equation to determine an approximate value for TDS. The main aim of the salinity trials was to assess whether salts accumulated over time within the RET channels, and if so at what rate. This information was needed to make an assessment on the sustainability of the RET system. If salts accumulated quickly and could not be managed it is possible that the RET system would not make the minimum 15 years sustainable life required by the relevant legislation (WS/13/1 2000).

The pH represents the hydrogen ion concentrations and is important water quality parameter as it describes acidity and alkalinity (Tchobanoglous and Burton 1991). If the effluent is outside of the pH range 6-8 the wastewater may be difficult to treat and have adverse effects on microorganisms and irrigated plants (Tchobanoglous and Burton 1991). The pH range of the wastewater is also important in regards to the microbiological transformation of ammonia and the bioavailability of nutrients to plants (Jones and Hood 1980; Piceno and Lovell 2000). The pH range of the effluent in the RET systems needed to be established to determine if the range was maintained at a sustainable level or if it altered and became a potential limiting factor.

Dissolved oxygen (DO) is required for the aerobic bacteria present in the RET system. Early observational trial studies before CQU became officially involved with the RET study showed that the soil in the channels became acidic (pH tests ranged between 3.5 to 5.5) when anaerobic effluent was pumped through the RET system that. Low soil pH values have toxic effects on plants and make many plant nutrients biologically unavailable (Hopkins 1999).

The venturi aeration system was added to the pump-line before the RET channels and soil pH values at the Rockhampton site increased to near neutral pH (7) within two weeks. Oxygen is only partially soluble in water and the oxygen holding capacity of the water is strongly influenced by temperature and salinity. The higher the temperature and the greater the salinity concentration the less oxygen holding capacity will be present in the sample of water (Tchobanoglous and Burton 1991). The aim of the DO water quality tests was to ensure that the aeration systems were working and to examine the impact that temperature and salinity accumulation had on DO concentrations. The temperature of the effluent was measured so that this comparison could be made and to establish whether any variation in temperature occurred within the RET systems over time.

3.3.1 Material and Methods

There were three water quality trials conducted at the test sites that related to salinity, pH, dissolved oxygen (DO) and temperature. The first involved a long-term accumulation where the holding tank effluent of all eight experimental sites was examined over time. The second trial was conducted at the Rockhampton trial site and examined what variations salinity, pH, DO and temperature underwent over a continuous 100-hour period. The third trial also took place at the Rockhampton test site and it measured the impact that tank pump-outs and a 3000 L influx of freshwater had on the salinity, pH, DO and temperature.

Two TPS™ meters were used to establish pH, salinity, DO and temperature. The first meter a TPS™ WP81 measured pH, EC (μS), TDS (ppm), while the second meter a TPS™ WP90 measured DO (ppm) and temperature (°C).

In the long-term accumulation holding tank study the samples were taken and analysed in the following manner. The holding tank at each site was examined once every three-months. A Van-Dorn sample collection device was used to take samples at the top, in the middle, and 500 mm off the bottom of the holding tanks. A Van-Dorn sample collection device can be triggered to take samples at selected depths. Samples were taken at different depths to control for any stratification of effluent that may have occurred within the holding tanks. Three samples were taken at each depth and placed into a 200 ml container that had a depth of at least 100 mm. The two TPS™ meters were used to test the samples at the site. Prior to leaving CQU the

TPS meters™ were calibrated according to the methods described by the manufacturer. Probes were inserted to a minimum effluent depth of 80 mm and were left within the effluent until a stable reading was achieved. Probes were washed with distilled water between each test. Samples were tested within 20 minutes of being collected. The results from each sample were recorded and are presented as the average readings of the total number of tests performed in each holding tank for each parameter.

In the second trial which investigated the variations in salinity, pH, DO and temperature over a 100-hour period the same eleven sample points used in the nutrient variation trial were used. These sample points were:

1. Untreated greywater – taken from the top of the vertical greasetrap
2. Treated greywater – taken from the discharge point of the vertical greasetrap
3. Septic – taken from the discharge point of the septic tank
4. Holding tank – taken from 500 mm off the bottom of the holding tank
5. Non-transpired effluent – taken from the return line from the RET channels
6. Bamboo WS – herring bone RET channel planted with bamboo closest to workshop
7. Bamboo RD - herring bone RET channel planted with
8. Heliconia – herring bone RET channel planted with Heliconias (gingers)
9. Citrus – channel-to-channel flow-through RET channel planted with citrus
10. Banana - channel-to-channel flow-through RET channel planted with banana

11. Pump-well – taken from 500 mm from the bottom of collection tank for the non-transpired effluent prior to it being pumped back to the holding tank

Three samples were taken from each sample point; with each sample having a minimum volume of 200 ml. All three samples were analysed using the two TPS™ meters according to the method previously described, within 40 minutes of being taken, with the results being reported as an average. It is acknowledged that some change in temperature may have occurred during this time but the analysis on the 33 different samples could not be performed in a shorter period of time. Samples were analysed in different orders to try and minimise the effect of temperature change. This trial was conducted during December 1999 and was run concurrently with the 100-hour nutrient variation trial. It was not repeated in December 2000 due to a lack of human resources. The TDS results were recorded but are not presented in this thesis, because the EC data provides the same information.

The third trial examined the impact on salinity, pH, DO and temperature that tank pump-outs and a 3000 L freshwater flush had on the Rockhampton RET system. The trial occurred on the first Wednesday in November 2003. This was after the long-term accumulation trial had been completed. The eleven sample points used in the 100-hour variation trials were used for this test. The sampling and analysis method used for the 100-hour variation trial that examined salinity, pH, DO and temperature was repeated. However the effluent was only examined for eight hours.

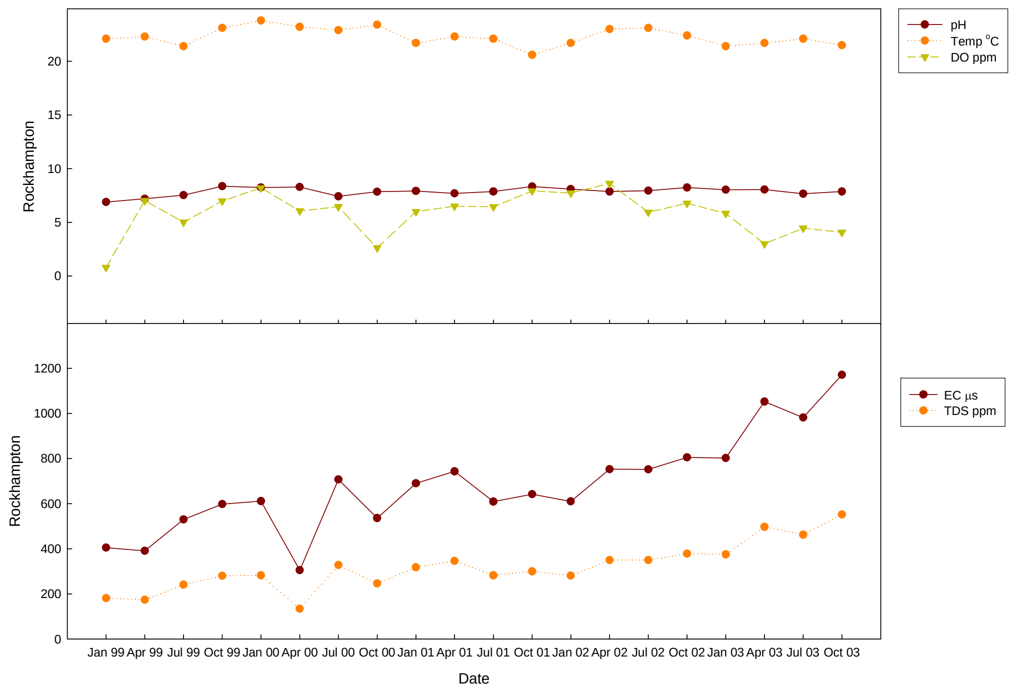
Four hours worth of tests were performed on the effluent from the eleven samples points. In between the 4th and the 5th hours the septic tank, vertical greasetrap, holding tank and pump-well were all pumped out so that only a ¼ of the previous volume remained. This volume of effluent was kept to help ensure that the microorganism cultures that had developed in the various treatment stages of the RRET system were retained.

The septic tank and the vertical greasetrap were then filled to just below their respective effluent discharge points with reticulated town water. Then 3000 L of reticulated town water was added to the holding tank. While this water was added the pump was engaged and water was continually pumped through the RET channels. After approximately 2000 L of reticulated water had been added to the holding tank a mixture of reticulated water and non-transpired effluent was returned to the holding tank through the return line from the pump-well.

The pump-out of the tanks and the addition of the 3000 L of reticulated town-water took approximately 40 minutes. The pump in the holding tank was kept running until the end of the hour. Samples were then taken once an hour for the next fours hours from all 11-sample point and analysed using the methods and equipment previously described. The main aim of this experiment was to test whether accumulated salts could be leached out of a RET channel system.

3.3.2 Rockhampton site

Figure 3.9 presents the results from the long-term salinity, pH, DO, and temperature study conducted on the effluent in the holding tank at the Rockhampton site.



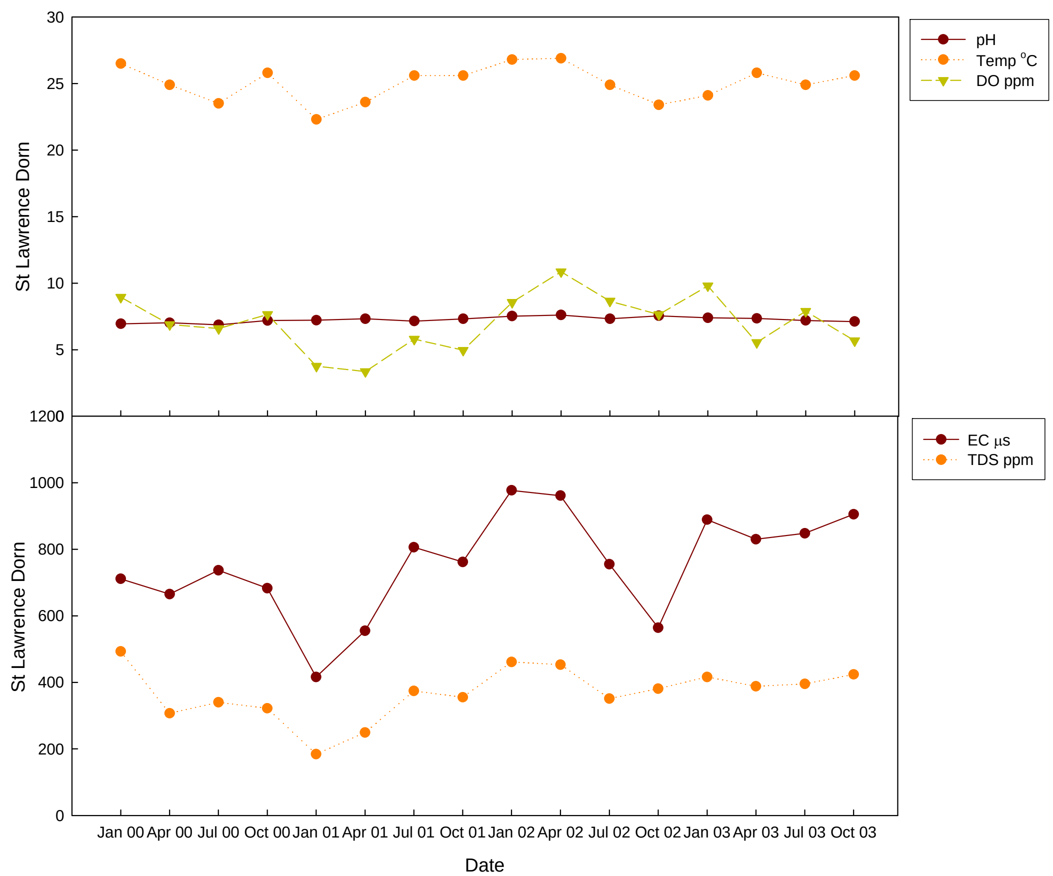
The pH range at this site was generally between 7.5 and 8.3; this was relatively alkaline compared to average domestic wastewater (Tchobanoglous and Burton 1991), but this can be accounted for by the inputs of cement and lime industrial waste both of which are highly alkaline. Salinity concentration accumulated over time, although there was a reduction in April 2000. At this time a float valve in a toilet at the site malfunctioned and added approximately 6000 L of reticulated town-water to the system. This malfunction occurred twelve days before the tests were performed. Salinity concentration within the system decreased because some of the excess water that was added to the system was disposed of through the emergency overflow, allowing salts to exit and not be recirculated. The temperature in holding tank remained constant and had no marked deviations. The initial low DO reading in January 1999 was related to a malfunction in the aeration system. The DO decreased in the last year as salinity concentrations accumulated past 1000 μS.

3.3.3 St Lawrence domestic site

The selected water quality for the St Lawrence holding tank are presented in Figure 3.10. The pH showed very little variation and occurred predominately in the range 6.8-7.5. The salinity showed yearly decreases in the summer months. In periods of torrential rain the emergency overflow at this site filled up with stormwater. The holding tank had unknown quantities of stormwater enter through the emergency overflow.

This diluted the effluent within the holding tank and also meant that some effluent was disposed of through the emergency overflow. The direction of the emergency overflow was changed in late 2001, and when that was not effective, diversion banks to prevent stormwater runoff over the emergency soakage drain were constructed in late 2002. These proved effective in 2003 with no recorded stormwater intrusion. Salinity did not steadily accumulate in this system, but it is expected that it will now that the flooding issue has been resolved.

Figure 3.10 Salinity, pH, DO, and temperature long-term accumulation study in the holding tank at the St Lawrence domestic site



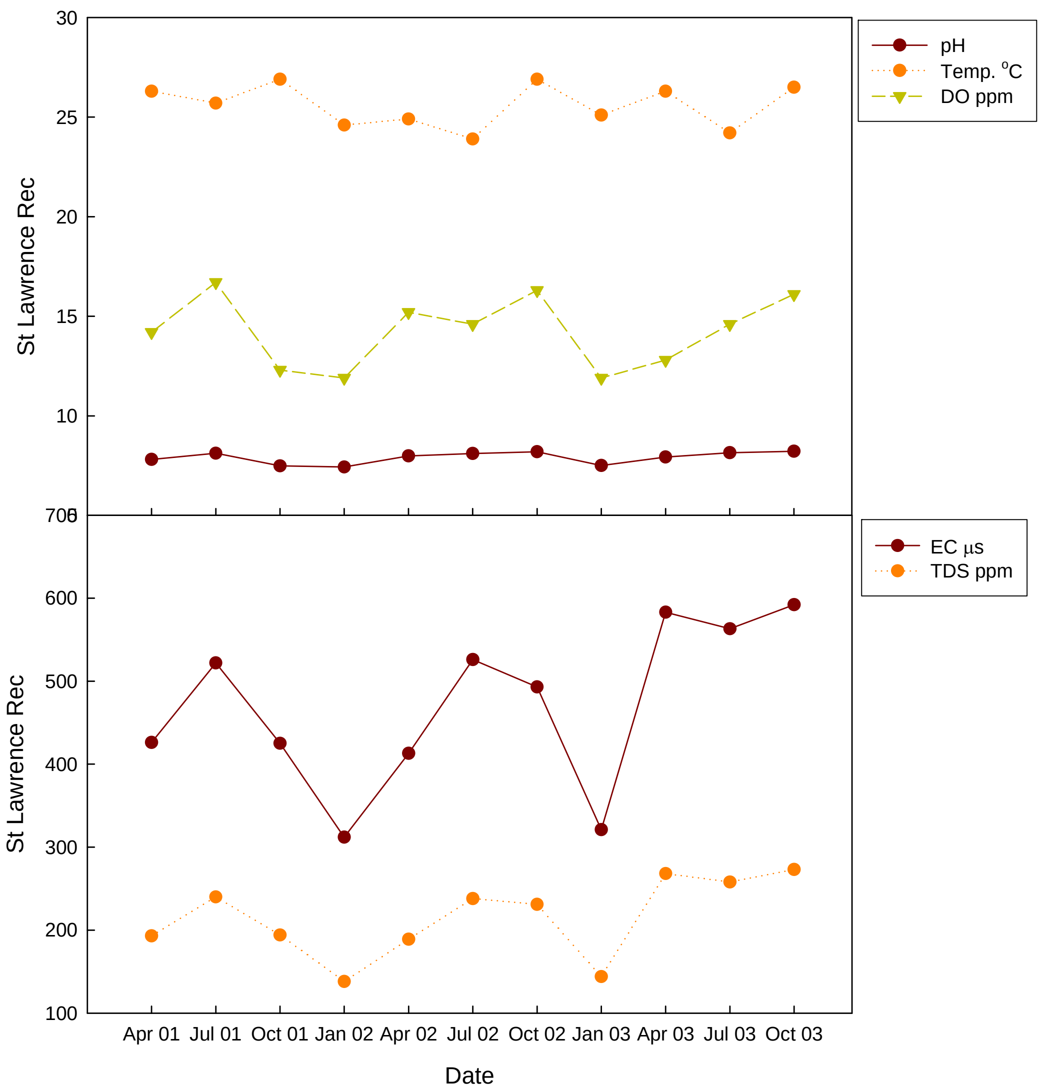
The DO rates peaked in April 2002, which was not expected as the temperature and salinity rates were relatively high, indicating that the DO concentrations should have been reduced (Tchobanoglous and Burton 1991). What caused this small peak in DO is not known. The temperature of holding tank effluent at this site averaged at just below 25 °C. The DO concentration did decline slightly in 2003 when salinity and temperature increased; this followed the normal relationship between the three parameters.

3.3.4 St Lawrence recreation area

The selected water quality data for the St Lawrence recreation area are in Figure 3.11. The pH range was in general between 7 and 8. In January of each year the concentration of salts in the holding tank decreased dramatically. This was due to a large horse sports festival held at the recreation ground at this time. Over 400 people camped at the recreation area for two days for the horse sports activities. No additional amenities were supplied at the site and the treatment systems underwent massive hydraulic shock loads. The RET system was not able to cope with the volume of wastewater and overflowed into the AWTS. The large volume of inflow wastewater diluted concentrations of salts within the RET system and the disposal of the excess effluent to the AWTS prevented the long-term accumulation of salts.

Salinity decreased in small amounts at other times due to shock-loads of effluent during the peak of the winter month tourist seasons. These small-shock loads resulted in excess effluent leaving the RET system and being treated by the AWTS. Salinity did not dramatically increase in this system. The temperature of the effluent averaged at about 26°C, and did not seem to correlate with the seasons. The DO concentration at this site did not follow the normal relationship between DO, salinity, and temperature. The DO ppm reduced when the salinity concentrations were relatively low; this is the opposite of what theoretically should have occurred.

Figure 3.11 Salinity, pH, DO, and temperature long-term accumulation study in the holding tank at the St Lawrence recreation area

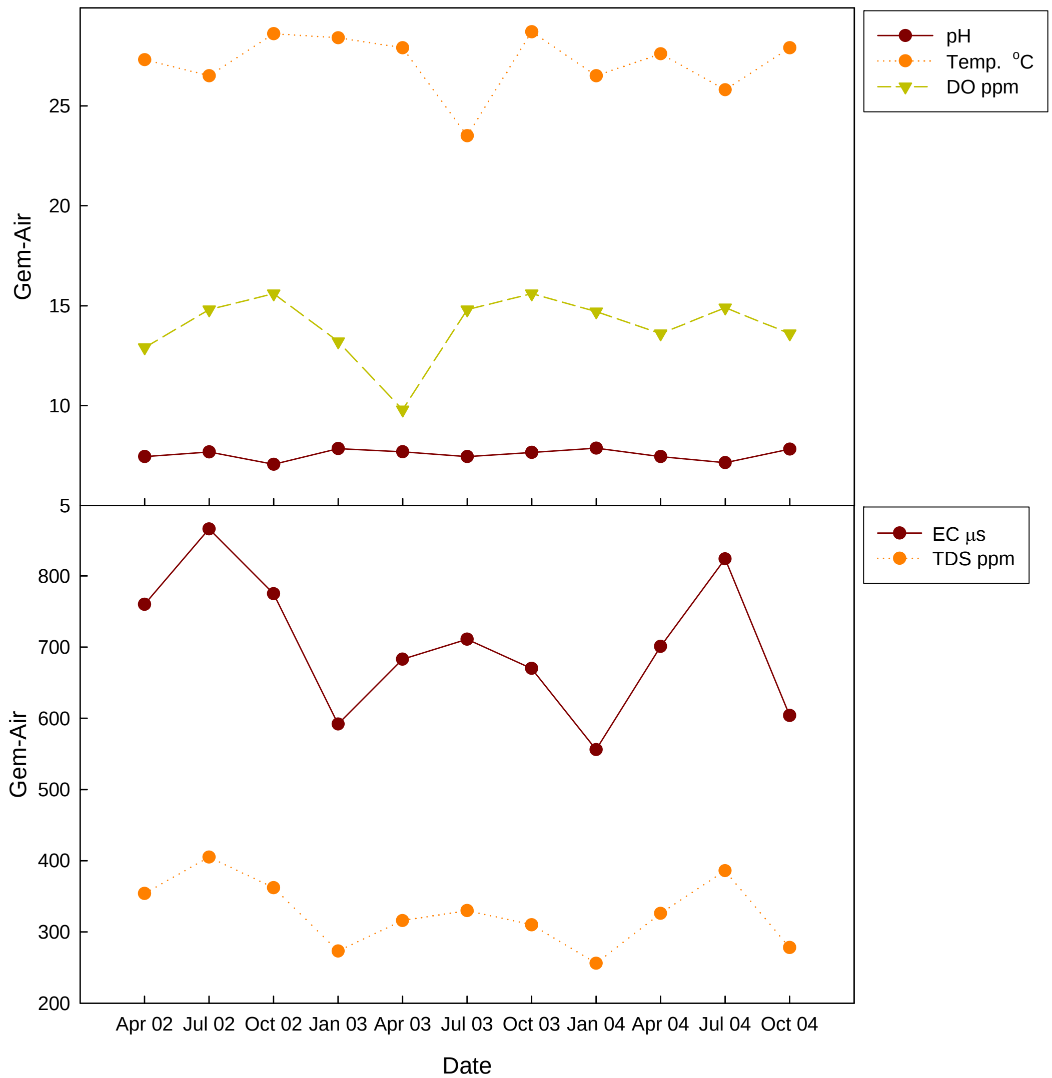


This site had the first of the new venturi valve systems that were located within the holding tank. The new venturi system diverted half of the oxygenated effluent flow back into the holding tank. The physical mechanism of the venturi valve powered through the pressure of the pump was able to dissolve more oxygen in any given water sample than would occur through mechanically unaided diffusion. It appeared that the DO concentration at this site was strongly influenced by the amount of venturi valve returned effluent present in the holding tank at the time the test was conducted.

3.3.5 Gem-Air caravan park

The salinity, pH, DO, and temperature of the effluent in the holding tank at the Gem-Air caravan park are reported in Figure 3.12. These water quality tests were conducted year-round, including the non-tourist season. The pH readings were consistent and ranged between 6.8 and 7.6. This RET channel system was not designed as a closed recirculatory mechanism; but rather diverted excess effluent into additional treatment stages. The salinity concentrations peaked in the tourist season and decreased dramatically in the warmer non-tourist months. The salinity concentrations did not increase in the 2003 tourist season to the same extent as in the other two years. In 2003 the entire area was drought declared and water was transported from Emerald ($\approx$ 80km). This water had a lower quantity of salts ($\approx$350 μS) then the groundwater normally used at Gem-Air ($\approx$500). It is thought that the salinity did not increase to the same extent in 2003 due to the smaller quantities of salt put into the wastewater. This site had a new-style venturi valve and it is thought that this impacted on the DO concentrations in the holding tank. The relationship between DO, salinity, and temperature was not followed; it is thought that the oxygenated effluent returned to the holding tank by the venturi valve increased the DO ppm in the effluent.

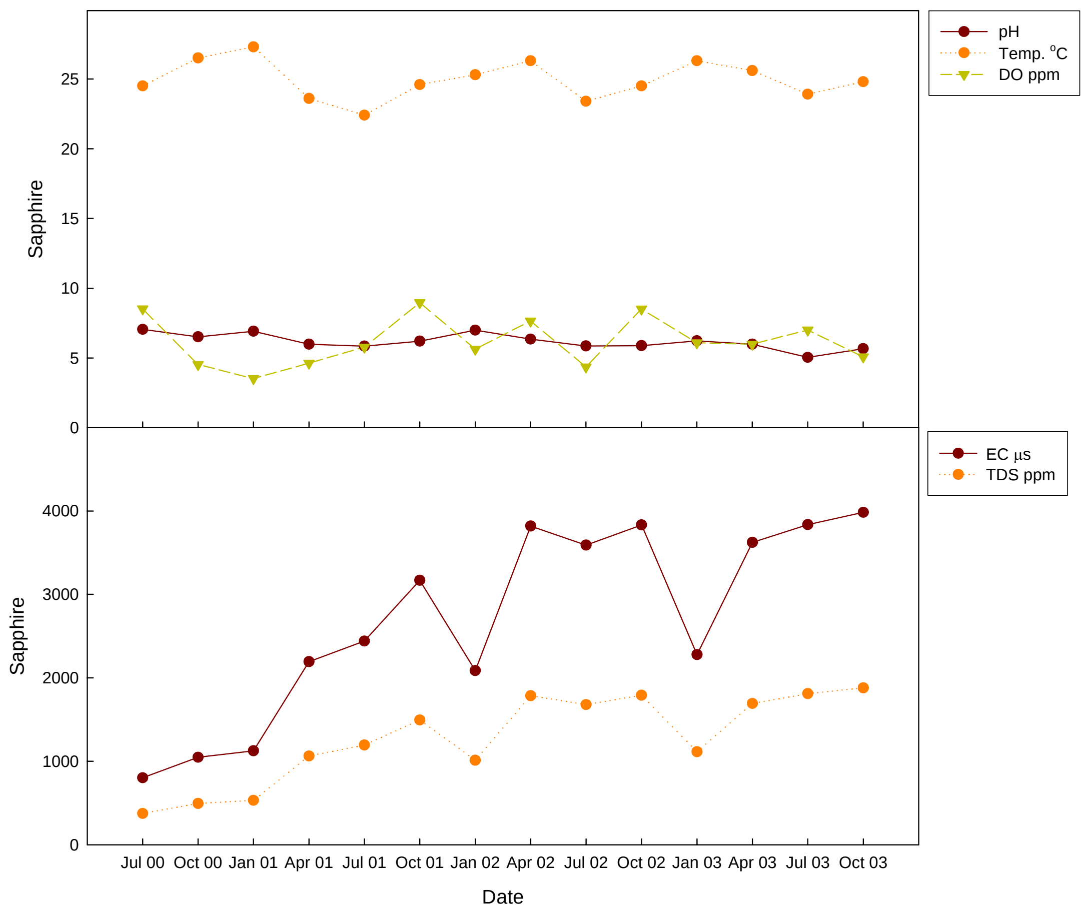
Figure 3.12 Salinity, pH, DO, and temperature long-term accumulation study in the holding tank at the Gem-Air caravan park



3.3.6 Sapphire site

Figure 3.13 shows the data on salinity, pH, DO and temperature for the holding tank effluent at the Sapphire site. The pH at this site decreased over time and in general ranged between 5 and 6.1. It is thought that the strong acids in the chemical toilet reagents lowered the pH. In January 2002 and January 2003 wet weather events filled the emergency soakage drain and stormwater infiltrated the holding tank. The volume of stormwater that entered the holding tank could not be calculated. Within three-months the EC concentrations had accumulated to between 3000 and 4000μS. Salts accumulated in this holding tank effluent at unsustainable concentrations.

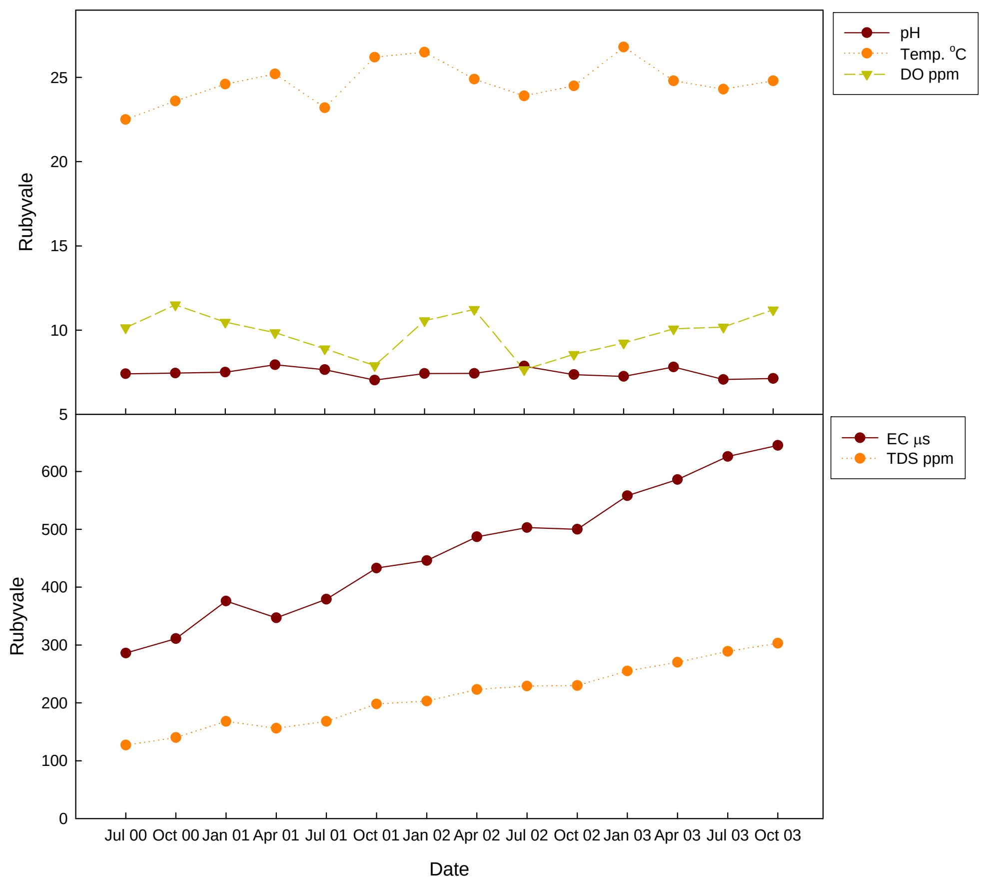
Figure 3.13 Salinity, pH, DO, and temperature long-term accumulation study in the holding tank at the Sapphire site



3.3.7 Rubyvale site

The selected water quality data for the effluent in the holding tank at the Rubyvale site is presented in Figure 3.14. The pH at this site ranged between 6.5 and 7.5 and averaged about 7.

Figure 3.14 Salinity, pH, DO, and temperature long-term accumulation study in the holding tank at the Rubyvale site

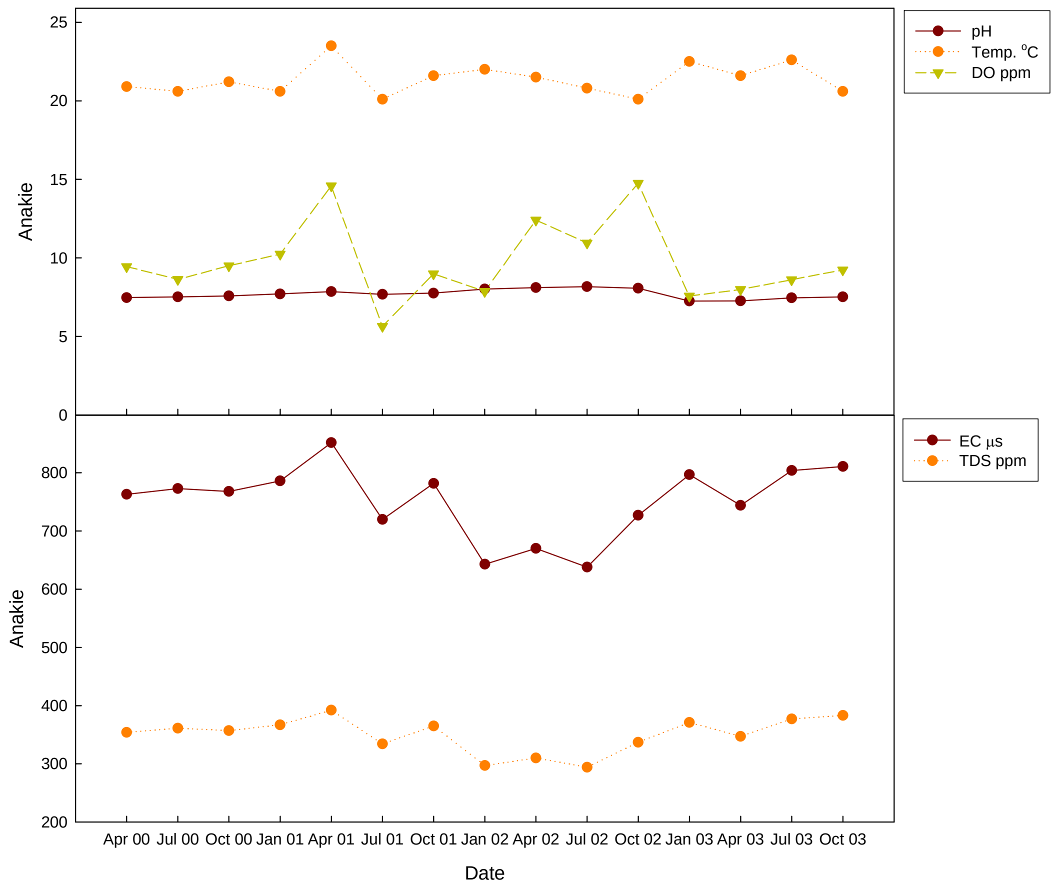


The salinity at the site slowly increased over time; the EC rose in just over three-years from 283 µS to 633 µS. This was an increase of approximately 125 µS per year. This may be a sustainable increase if the accumulation rate is maintained and a maintenance procedure that leaches the salts from the RET channels is performed once every five years. The DO concentration was relatively constant with no striking variations, and in general followed the relationship between DO, salinity, and temperature.

3.3.8 Anakie site

The selected water quality data of the holding tank treated greywater at the Anakie site is presented in Figure 3.14. The range of the pH data at the site showed no marked deviations with a near-neutral average reading. Salinity did not steadily accumulate at this site. This system was based at the Anakie semi-independent retirement home and wastewater production could vary greatly depending on the clients in the home and what care they received. During the visits of staff (nurses and cleaners) multiple showers and laundry loads could be conducted in a relatively short time which resulted in a hydraulic surge through the vertical greasetrap and into the RET system holding tank. Occasionally this triggered the emergency overflow and resulted in effluent being disposed of from the system. This may have prevented salts from accumulating within the system over-time. The DO concentrations varied greatly for no discernible reason. Twice (July 2001 and January 2003) the venturi valve at this site needed maintenance due to insects building nests in the air inlet. The temperature range at this site was between 20 °C and 24 °C.

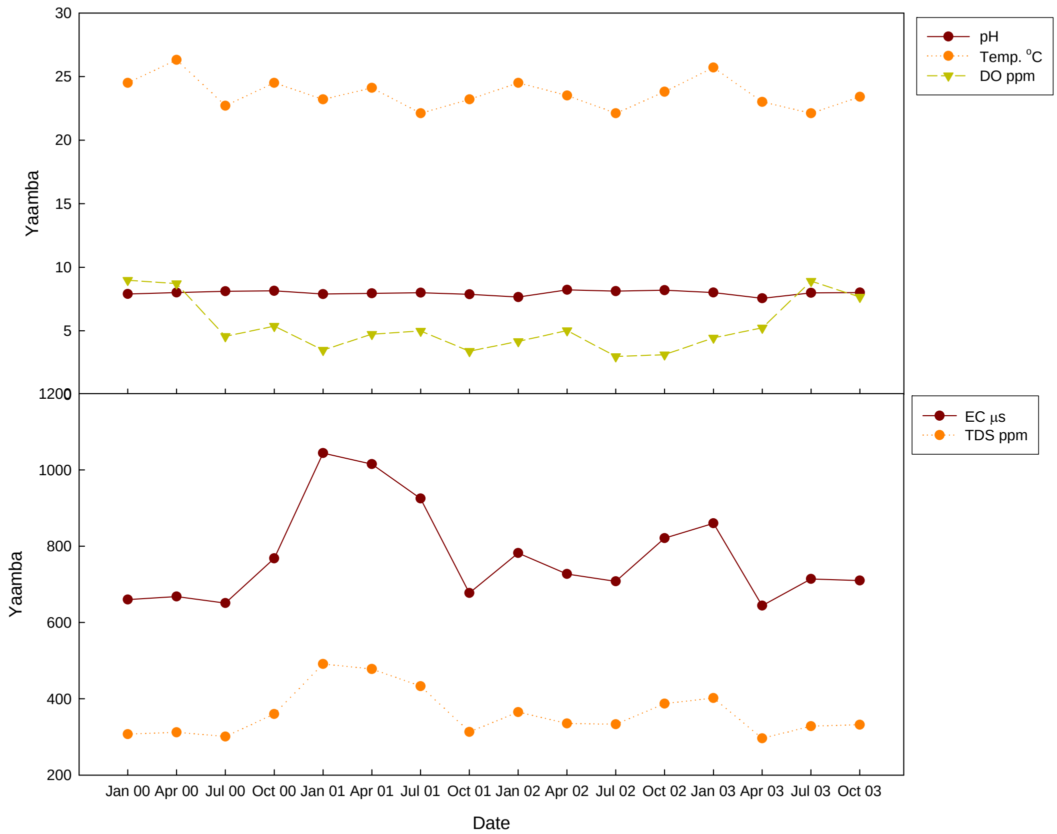
Figure 3.15 Salinity, pH, DO, and temperature long-term accumulation study in the holding tank at the Anakie site



3.3.9 Yaamba site

Figure 3.16 describes the selected water quality data for the effluent in the holding tank at the Yaamba site. The pH at this site ranged between 7.5 and 8.6; this may be due to the alkaline bore-water used at the site. This site was situated on the Yaamba flood plain and the emergency soakage drain was susceptible to intrusion from stormwater runoff. It is the dilution impact of stormwater intrusion and the associated disposal of recirculated effluent from the system that may have prevented salinity from steadily accumulating. The DO concentration declined when salinity peaked and the average temperature was 24.3 °C. The relationship between DO, salinity, and temperature was within the normal range (Tchobanoglous and Burton 1991).

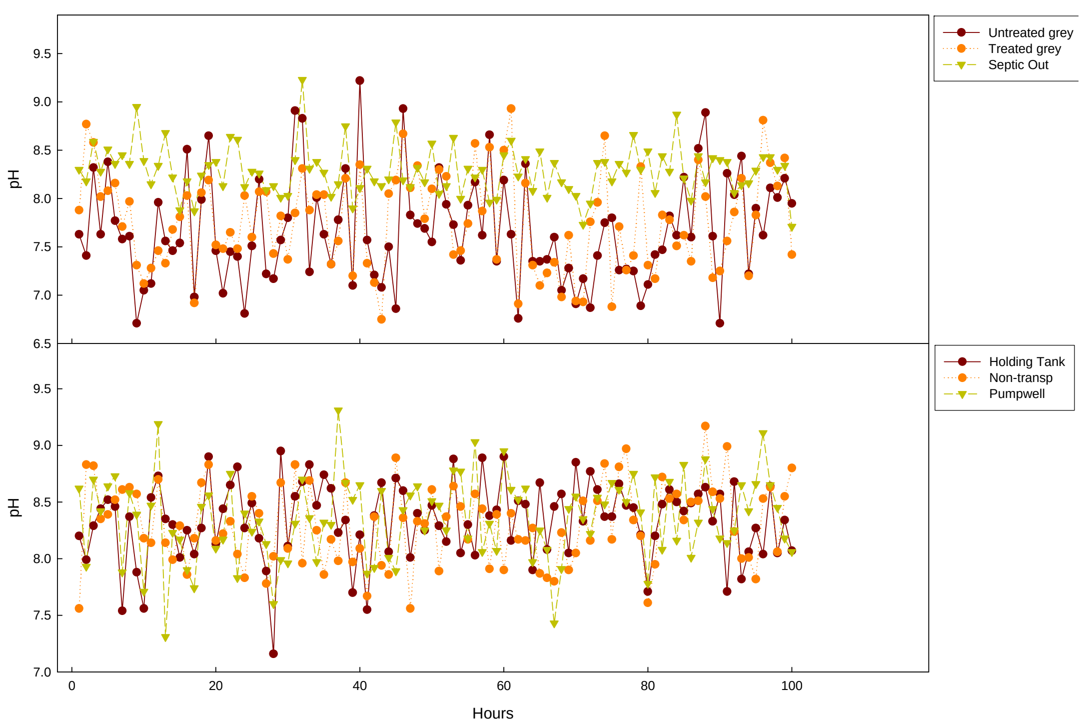
Figure 3.16 Salinity, pH, DO, and temperature long-term accumulation study in the holding tank at the Yaamba site



3.3.10 Rockhampton site 100-hour pH, Temperature, DO, and Salinity Trial

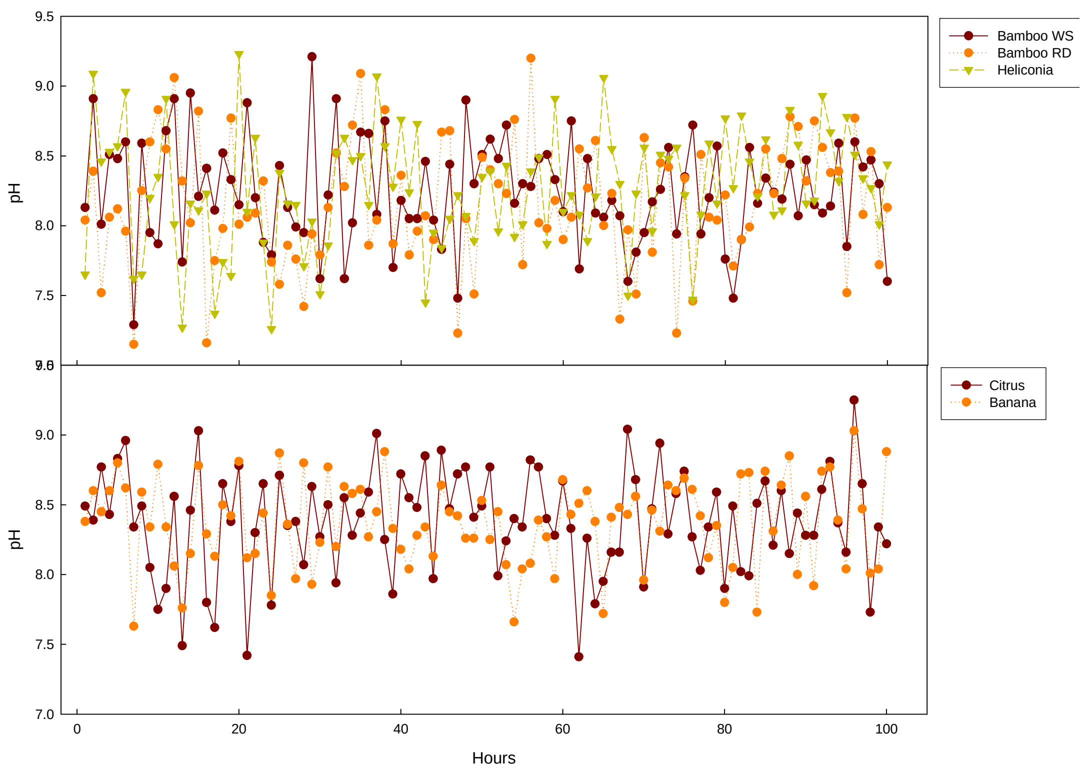
The pH ranges in the eleven trial sites over the 100-hour trial are shown in Figures 3.17 and 3.18. The majority of the results from all test points was alkaline; with only occasional weak acidic pH readings in untreated and treated greywater. The pH range of the untreated greywater went from 6.7 to 9.3 with an average 7.67 reading and standard deviation of 0.55. The treated greywater went from 6.7 to 9.0, with an average 7.76 reading and standard deviation of 0.50. There was little overall difference between the pH of the untreated and treated greywater.

Figure 3.17 The pH of the treatment tanks water and the non-transpired effluent over 100-hours



The septic tank discharge had an average pH reading of 8.28 and a standard deviation of 0.25. The pH of the septic discharge was consistently alkaline. The holding tank had a mean pH reading of 8.33 and a standard deviation of 0.34. There could be great variations amid the hours, such as between 25-to-26 hours the pH went from 7.1 to 9.0. The exact cause of these spikes is not known, but could be related to wastewater input or the chemical characteristics of the returned non-transpired effluent. The non-transpired effluent had an average pH of 8.34 and a standard deviation of 0.35, while the pump-well effluent had an average pH of 8.35 and a standard deviation of 0.37. There was very little difference in pH between the two types of non-transpired effluent, and the holding tank effluent.

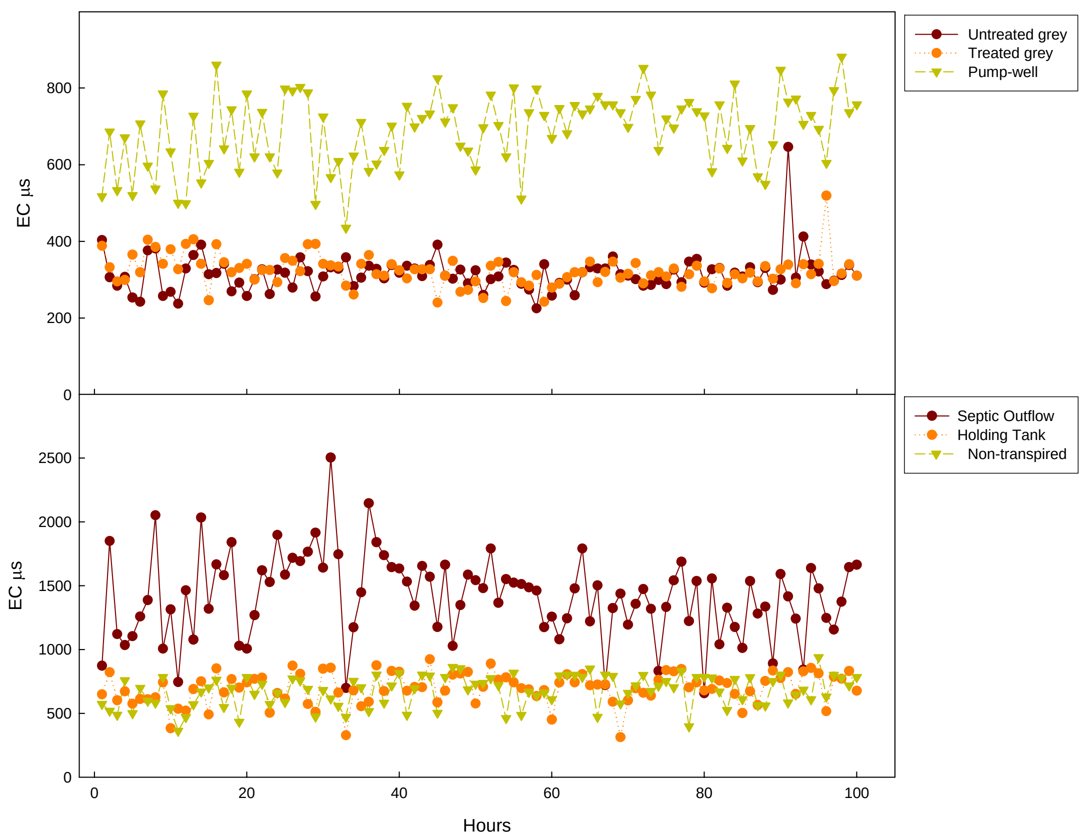
Figure 3.18 The pH of the effluent within the selected RET channels over 100-hours



The pH in all of the selected RET channels was alkaline and averaged in the pH 8 range. The pH in the RET channels did not remain consistent through the 100 hour-trial but varied within each channel by at least 2 pH units. The variation could take place within an hour or over several hours. The variation did not seem to occur at any particular time, that is during day/night or during work-periods or shutdowns. The bamboo WS had an average pH reading of 8.24 and a standard deviation of 0.37, and the bamboo RD had an average pH reading of 8.16 and a standard deviation of 0.44. It is thought that the different microenvironments within the RET channels, in regards to hydraulic flow and microorganism cultures, resulted at any-given time in the dissimilar pH readings. The heliconia RET channel had an average pH reading of 8.25 and a standard deviation of 0.42. The two channel-to-channel flow-through design RET channels, the citrus and banana, had a pH average of 8.37 and 8.36, and a standard deviation of 0.37 and 0.31 respectively. The regular hydraulic flow through these channels may have resulted in a more consistent pH reading.

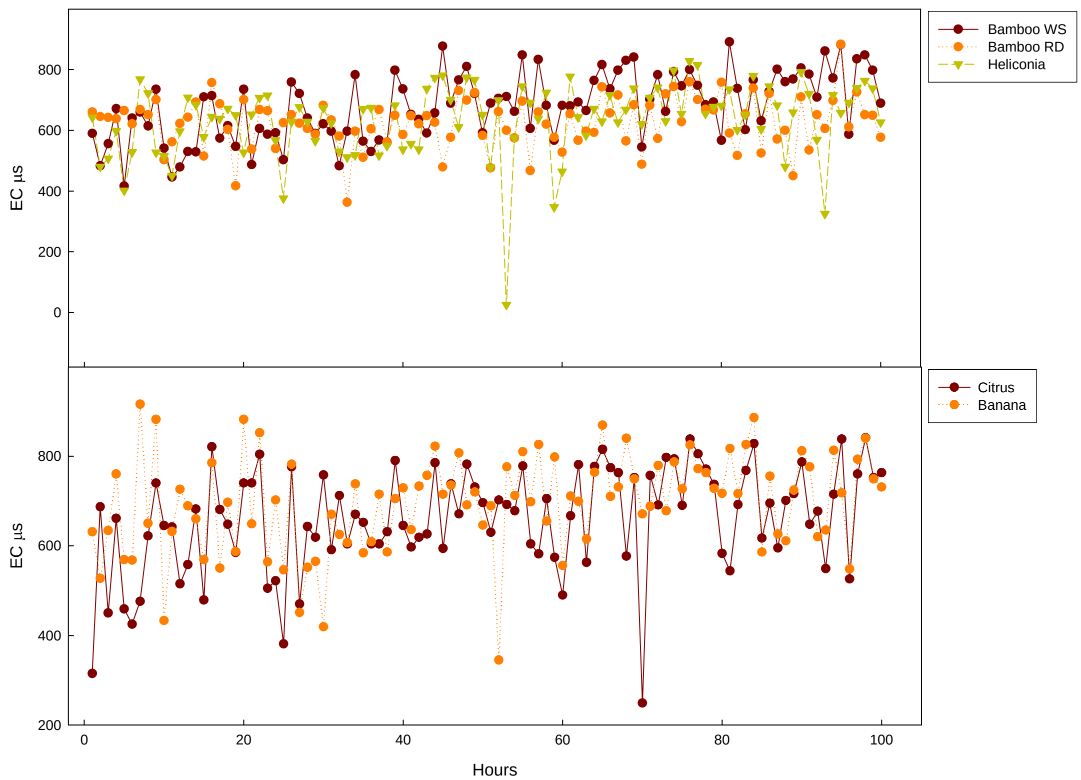
The EC of the eleven sample points are represented in Figures 3.19 and 3.20. The EC of the untreated greywater was 315 μS with a standard deviation of 49. The treated greywater had an EC of 322 μS and a standard deviation 40. At about the 90 hours period of the trial an unknown liquid waste with a high concentration of salts must have been added to the vertical greasetrap. The untreated greywater showed a marked increase in salinity that appeared in the treated greywater four hours later. The salinity of the two types of greywater was relatively consistent. The septic tank effluent had an average EC value of 1414 µS with a standard deviation of 328. The workshop was closed for the weekend between the 40th and 80th hours and the EC of the septic discharge was relatively consistent.

Figure 3.19 The EC of the treatment tanks effluent and the non-transpired effluent over 100-hours



There was a major decrease in salinity on the Friday before the shutdown. It was the employment practice to work through lunch on a Friday so that work was finished an hour earlier. This could mean that the amenities were used at a higher rate during the morning tea break on a Friday. This might have resulted in a small hydraulic surge through the septic tank of relatively low-salt concentration flush water. The holding tank effluent had an average EC concentration of 698 μS and a standard deviation of 121. The non-transpired effluent and the pump-well effluent had EC concentrations of 673 μS and 687 μS and standard deviations of 121 and 95, respectively.

Figure 3.20 The EC of the effluent in the selected RET channels over 100-hours



These EC concentrations were similar and in the main the three types of effluent followed the same patterns over the 100-hours. For the selected RET channels the EC averages and standard deviation were as follows

- Bamboo WS 679 μS (110 standard deviation)

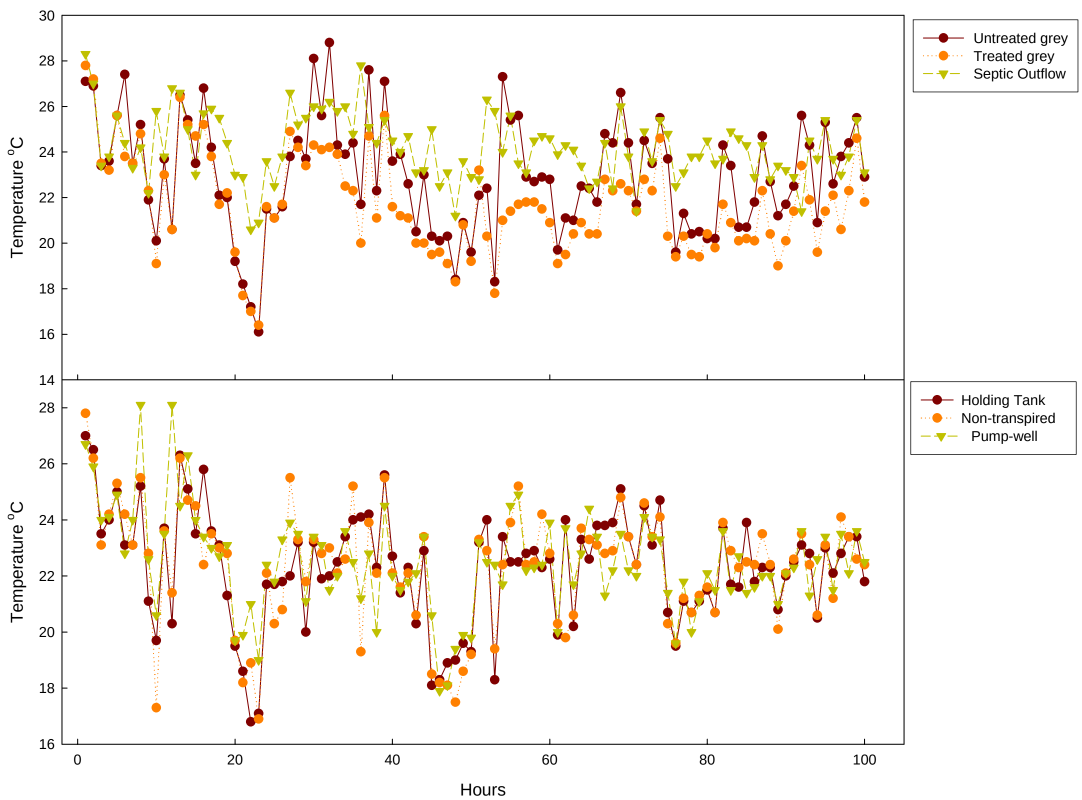
- Bamboo RD 625 μS (82 standard deviation)
- Heliconia 632 μS (120 standard deviation)
- Citrus 660 μS (118 standard deviation)
- Banana 695 μS (108 standard deviation)

The range of EC within the channels varied greatly, though overall the RET channels seemed to generally follow the same increases and decreases in salinity concentration. The pattern appeared to loosely follow the 3-hour pump cycle; with the highest salinity concentrations just after effluent had been pumped to the RET channels and the lowest salinity concentrations just before a new pump cycle was due to commence. It is thought that salts were transferred into the RET channel soil during the non-pump period, and that this is why salinity concentrations decreased. The heliconia channel had a dramatic decrease in the 55th hour that occurred to a lesser extent in the banana channel. The reason for this was unknown.

Less dramatic decreases, but which were still relatively substantial, in salinity occurred at other times in the heliconia, citrus, and banana; but not in either bamboo channel. The bamboo RET channels had fairly similar standard deviations to the other RET channels; however salinity in the bamboo situation had marked increases rather than decreases. It is not known why this occurred; it may be that the soil in the bamboo RET channels had a greater concentration of salts and could not take up the salinity in the effluent at as high a rate as the soil in the other channels.

The temperature data of the eleven sample points during the 100-hour trial are presented in Figures 3.21 and 3.22. The temperature of the untreated greywater and treated greywater averaged at 22.9 °C and 21.7 °C with a standard deviation of 2.5 and 2.2 respectively over the course of the trial. The treated greywater consistently had a lower temperature throughout the trial. This is expected as the design of a vertical greasetrap uses temperature stratification where the warmer effluent floats with a grease layer over a cooler section of greywater.

Figure 3.21 The temperature of the treatment tank effluent and the non-transpired effluent over the 100-hours



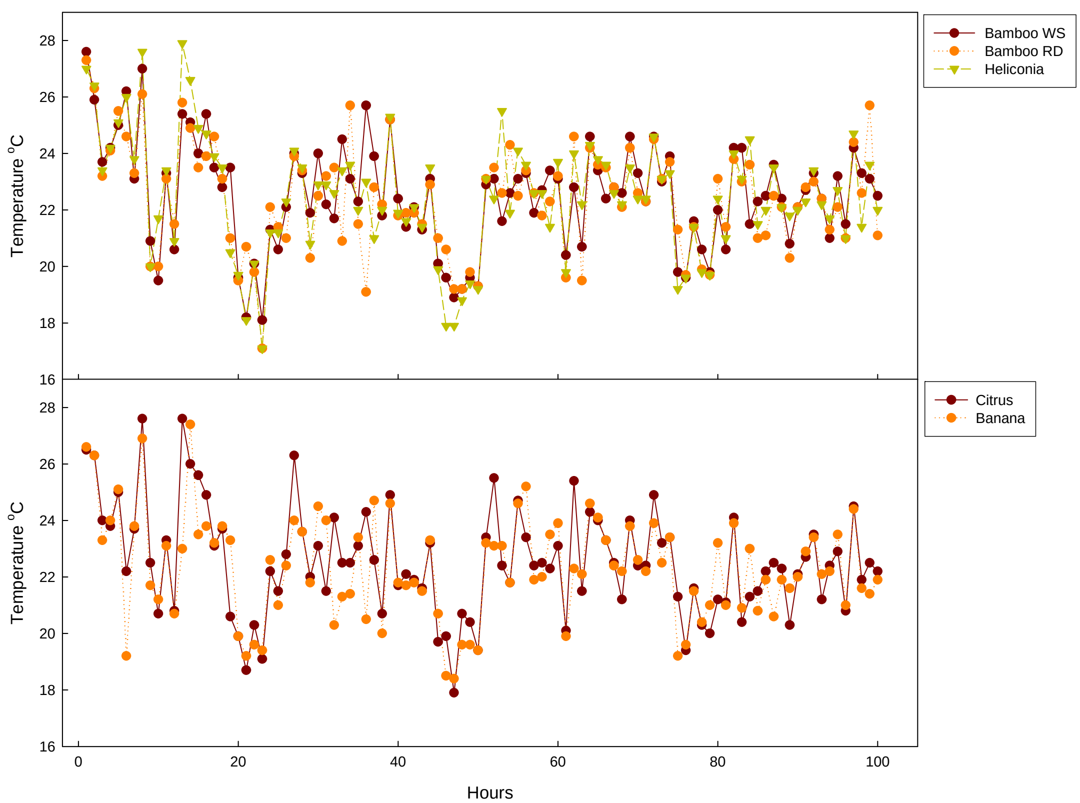
The temperature of the septic tank was stable with an average of 24.2 °C and a standard deviation of 1.5. The microbiological activity within the septic tank and the insulation provided by the scum and sludge layers may have assisted in keeping the temperature of the septic tank effluent constant. The holding tank effluent had an average temperature of 22.3 °C with a standard deviation of 2. The non-transpired effluent and the pump-well effluent had temperatures of 22.3 °C and 22.5 °C and a standard deviation of 2.1 and 1.8. There was very little variation in temperature between these three types of effluent. The main periods of low-temperatures were at around the 20th hour and 50th hour and both occurred before dawn during periods of light wind and rain. The rainfall and the relatively cool winds may have caused the temperature of the effluent to decrease in some of the tanks and the selected RET channels.

The average temperature and standard deviation within the selected RET channels was as follows:

- Bamboo WS 22.5 °C (1.9 standard deviation)
- Bamboo RD 22.4 °C (1.9 standard deviation)
- Heliconia 22.5 °C (2.1 standard deviation)
- Citrus 22.5 °C (1.9 standard deviation)
- Banana 22.3 ° C (1.8 standard deviation)

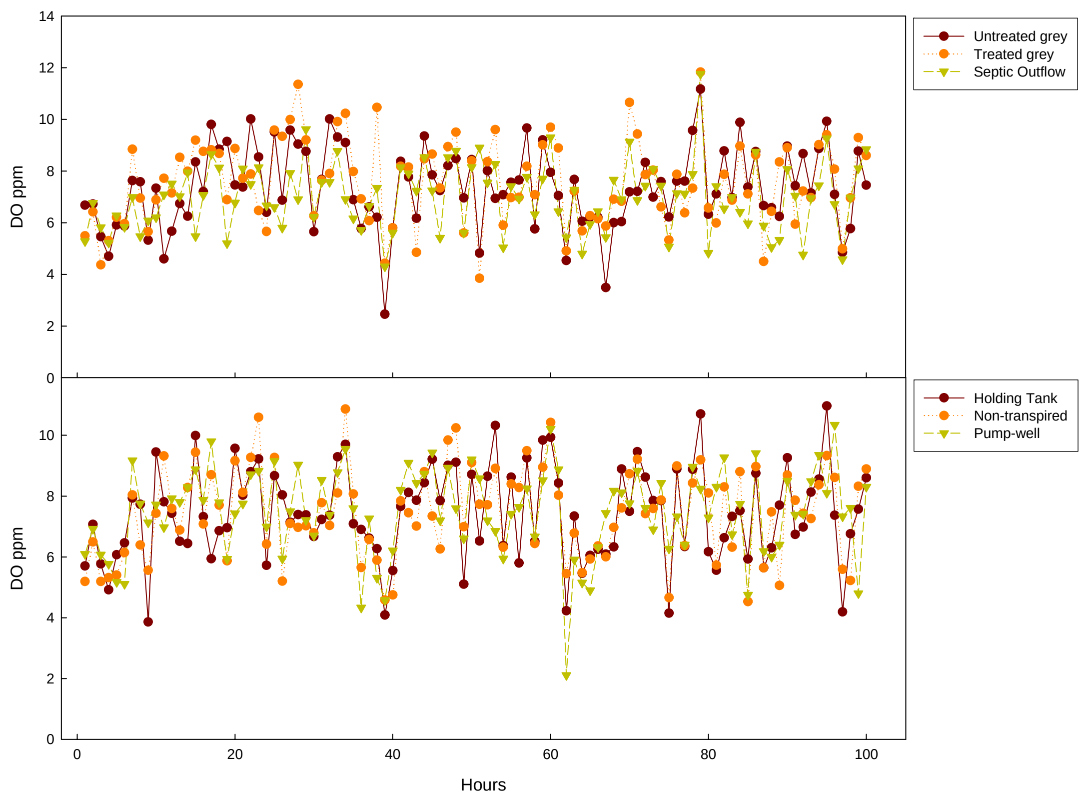
The average temperature between the selected RET channels was consistent. The effluent in all of the RET channels appeared to follow the same temperature patterns with very little temperature difference between the selected RET channel lengths at the same time.

Figure 3.22 The temperature of the effluent in the selected RET channels over 100-hours



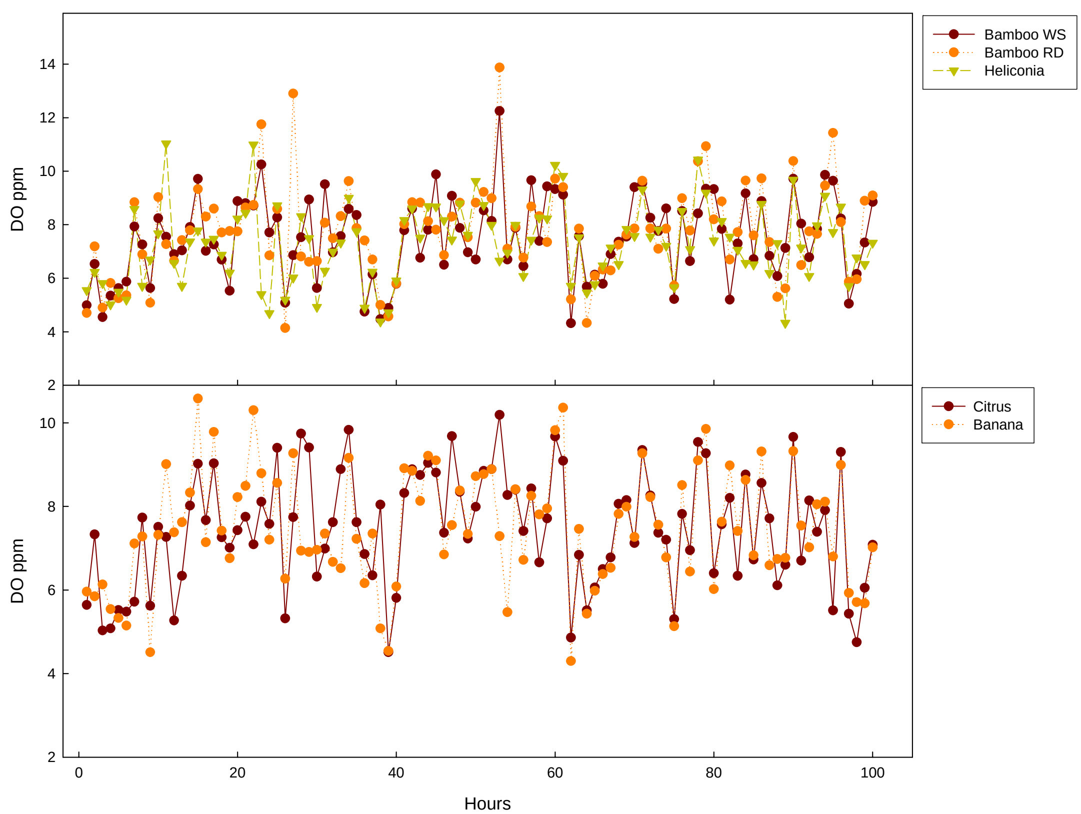
The DO concentration of the effluent from the eleven sample points in the 100-hour trial is presented in Figures 3.23 and 3.24. The untreated greywater had a DO concentration of 7.35 ppm and a standard deviation of 1.55. As expected due to the slightly lower temperatures the treated greywater had a small increase in average DO concentration to 7.56 ppm with a standard deviation of 1.63. The septic effluent discharge had an average DO concentration of 6.96 with a standard deviation of 1.31.

Figure 3.23 DO concentrations in the treatment tanks and non-transpired effluent over 100-hours



The holding tank had a DO concentration of 7.42 ppm (standard deviation of 1.54), the non-transpired effluent 7.42 ppm (standard deviation of 1.5), and the pump-well effluent 7.47 ppm (standard deviation of 1.44). These types of effluent had relatively consistent DO concentrations during the 100-hour trial. The effluent in the herring bone design RET channels achieved higher concentrations of DO, such as between 10 and 14 ppm, whereas the channel-to-channel flow-through design did not achieve any concentration higher than 10.8 ppm. The effluent had already passed through two channels before it reached the citrus channel and four channels before it reached the banana channel. In these initial channels oxygen may have been removed by biological processes or physical processes such as diffusion and this may have resulted in lower concentrations of oxygen in the citrus and banana channel lengths.

Figure 3.24 DO concentrations in the selected RET channel effluent over 100-hours



The average DO concentration and standard deviation within the selected RET channels were as follows:

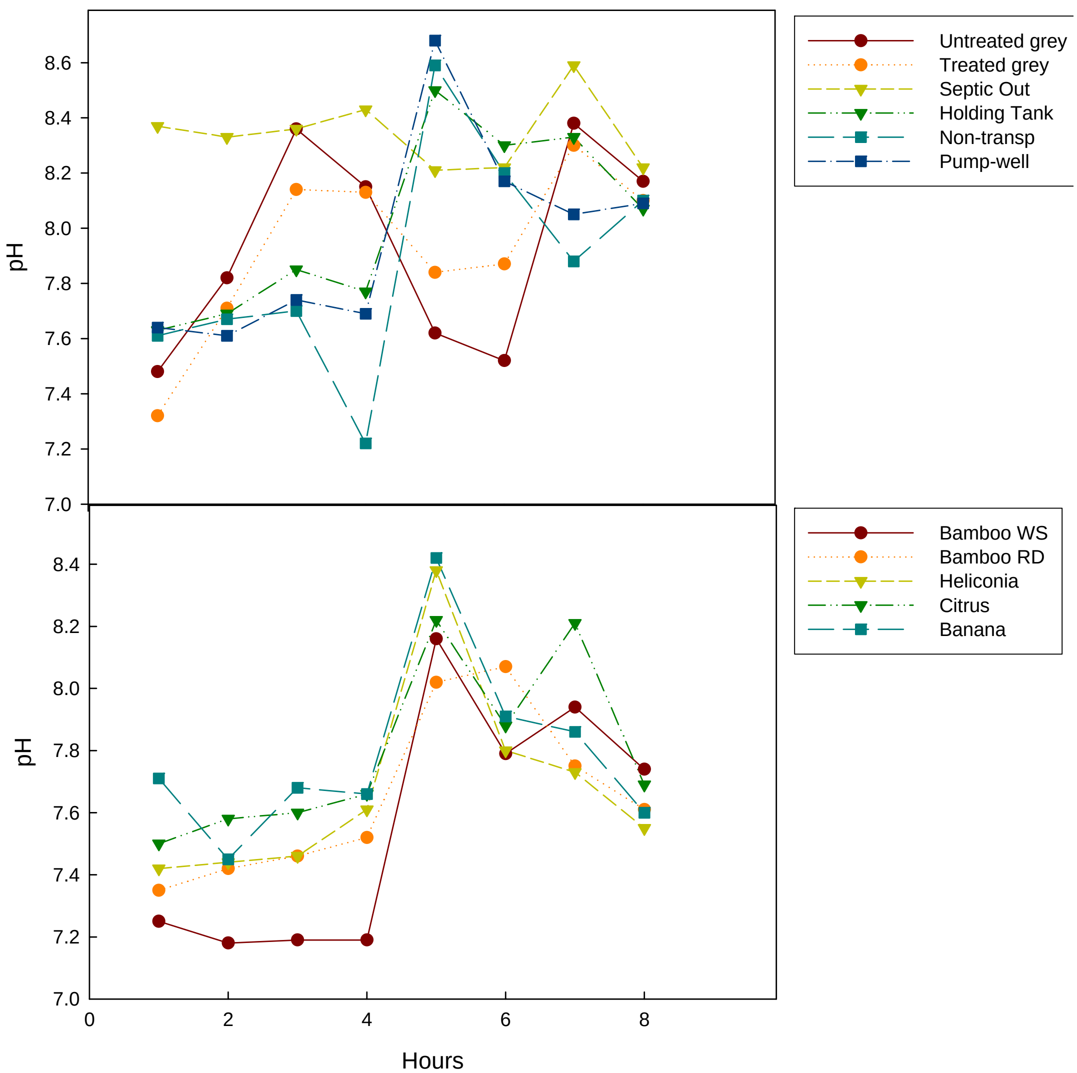
- Bamboo WS 7.49 ppm (1.54 standard deviation)
- Bamboo RD 7.76 ppm (1.75 standard deviation)
- Heliconia 7.27 ppm (1.46 standard deviation)
- Citrus 7.46 ppm (1.37 standard deviation)
- Banana 7.46 ppm (1.39 standard deviation)

3.3.11 Leaching trial at the Rockhampton site

The pH results from the leaching trial are presented in Figure 3.25. The pH of the untreated and treated greywater, and the septic discharge slightly reduced in pH between the 4th and the 5th hour when the reticulated town-water was added to the treatment tanks. During the same period the pH of the holding tank, pump-well and non-transpired effluent all became more alkaline. The reticulated town-water was approximately 1 pH unit more alkaline than the effluent that was previously in the holding tank and pump-well.

The pH in the selected RET channels rose in alkalinity between the 4th and 5th hour when the reticulated town-water was pumped through the RET system. An immediate decrease in alkalinity occurred after the pumping of the town-water ceased. In the 7th hour when the pump was triggered as part normal irrigation cycle the pH rose slightly in all RET channels. By the 8th hour the pH in the citrus, banana, and heliconia RET channels had returned to approximately the same values as at the start of the leaching trial while the bamboo channels were about half a pH unit more alkaline.

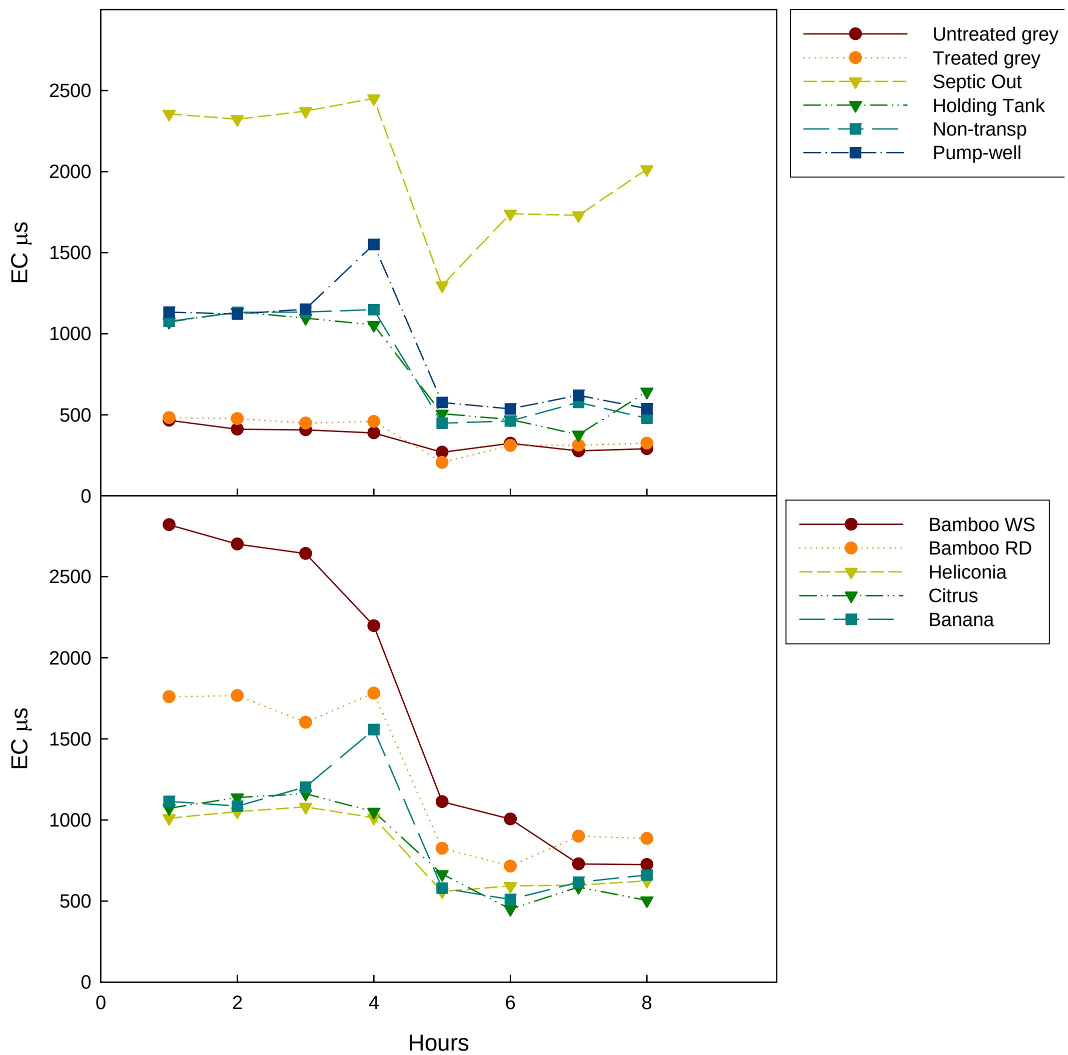
Figure 3.25 The pH of the effluent during the leaching trial



The EC data of the effluent in the RET system during the leaching trail is presented in Figure 3.26. The EC was slightly reduced in the untreated greywater and the treated greywater during the course of the trial. The EC of the reticulated town-water added to the RET system was 460 μS. This was close to the value EC of the greywater prior to the leaching trial; so no great change was expected. Between the

4^{th} and 5^{th} hour the septic outflow EC concentration decreased by about 1250 µS. The salinity in the septic discharge increased between the 5^{th} and 8^{th} hours until it was approximately 80% of the pre-leaching trial concentration. The EC concentrations of the effluent in the holding tank, pump-well, and non-transpired effluent all decreased by at least 50% between the 4^{th} and 5^{th} hour.

Figure 3.26 The EC concentration of the effluent tank during the leaching trial

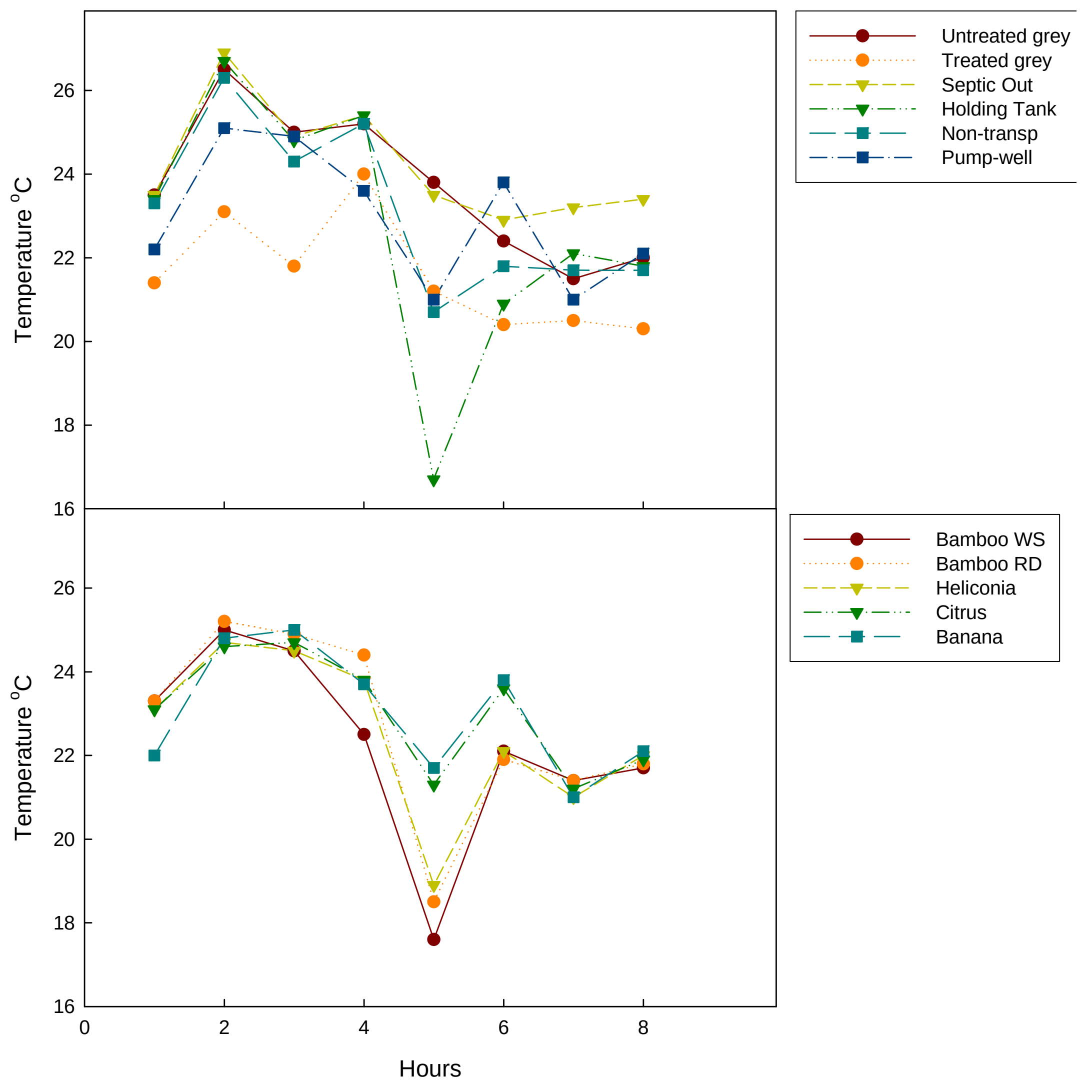


There was no marked increase in EC concentration in these sample points between the 5^{th} and 8^{th} hour. The salinity in the selected RET channels decreased dramatically between the 4^{th} and 5^{th} hour. All RET channels had approximately 50% decrease in EC concentrations after the reticulated town-water was added and salinity did not increase between the 5^{th} and 8^{th} hours. The 2000 L of effluent removed from the pump-well between the 4^{th} and 5^{th} is thought to have contained the salts that were removed from the RET system. A sample of the removed effluent had an EC concentration of 2437 μS.

The temperature of the different types of effluent during the leaching trial is presented in Figure 3.26. The temperature of all samples decreased between the 4^{th} and 5^{th} hour when the reticulated town-water was added to the RET system. The town-water had a temperature of 17 °C. This temperature was most closely reflected by the holding tank sample which had the greatest volume of town-water added.

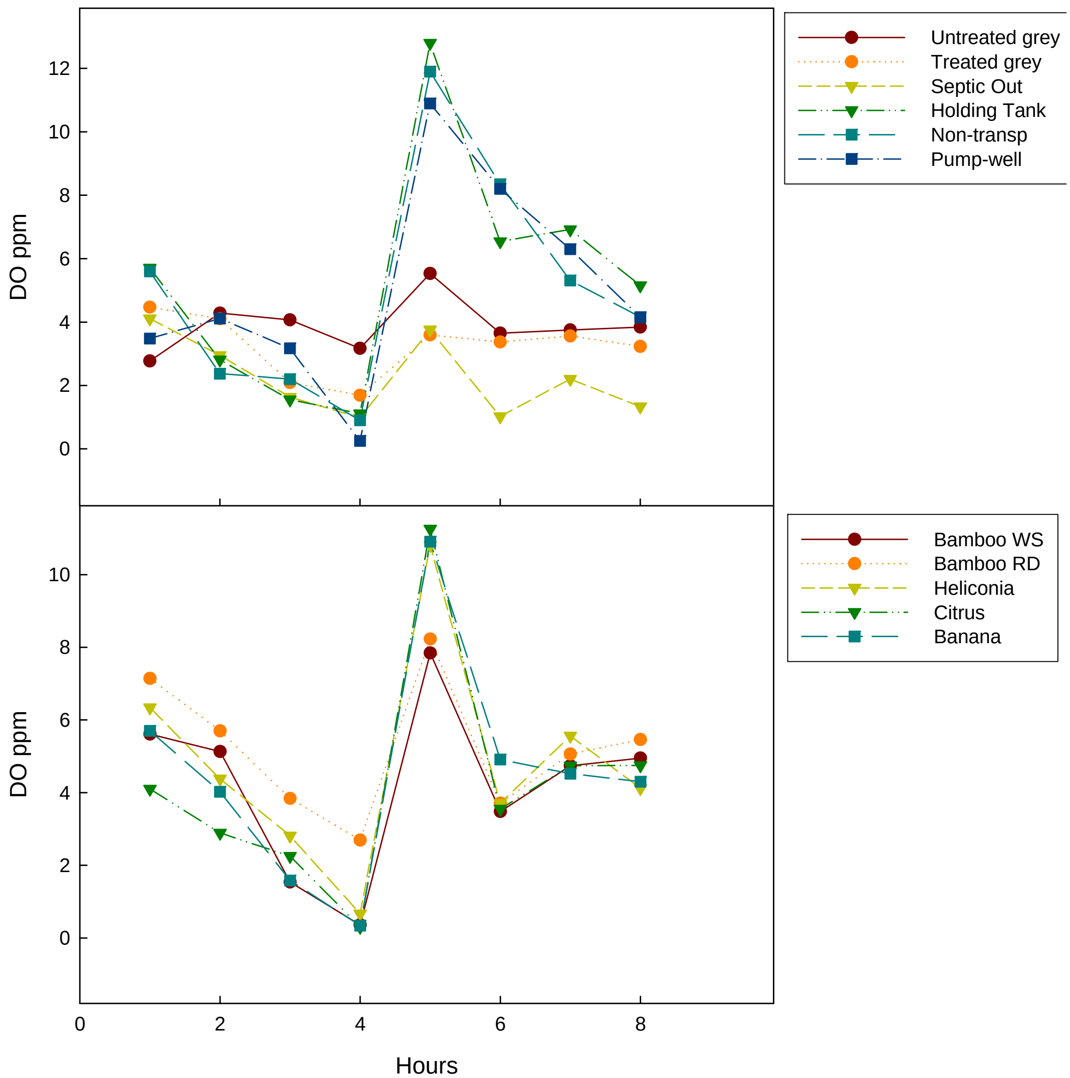
The temperature in the RET channels decreased during the pump-cycle in the 7^{th} hour were holding tank effluent of a lower temperature was pumped through the system. After the eight hours there was little variations between any of the samples and the original temperatures taken at the start of the leaching trial.

Figure 3.27 The temperature of the effluent during the leaching trial



The DO concentration of the effluent during the leaching trial is presented in Figure 3.27. Between the 4th and 5th hours the DO concentration curve for all the samples followed the relationship between DO, salinity and water temperature. At the time salinity concentrations and temperatures were at the lowest readings and DO ppm were at the highest. The DO concentration of the reticulated town-water added to the RET system was 11.2 ppm.

Figure 3.28 The DO concentration of the effluent during the leaching trial



With the reduction of salinity within the system it was expected that the DO concentration would increase in the holding tank, pump-well, non-transpired effluent, and the selected RET channels; however this did not occur, although DO did increase in the RET channels. It was observed that the pump-out of the tanks, the addition of the town-water, and the extended pumping period between the 4th and 5th hour did increase the amount of solids in the effluent. This was because sludge and scum layers were disturbed within the treatment tanks. Biofilms within the RET channels may also have released solids during the extended pumping period. These solids may have remained in the effluent for an extended period of time and reduced the amount of DO.

3.3.12 Discussion of Salinity, pH, Dissolved Oxygen and Temperature

The salinity experiments were the most important undertaken in regards to the sustainability of the RET system. With new inputs of salts expected with every aliquot of wastewater but with relatively very little of these salts being used by the microorganisms or the plants, salinity was expected to accumulate. As salts are toxic to plants and detrimental to soil structure if the salts accumulated too quickly the RET system would not be viable. Salinity did accumulate at all eight sites.

The Gem-Air site was of the least concern as the aboveground reuse of some of the treated effluent dramatically slowed the accumulation rate of the salts. The salt leaching experiment at the Rockhampton site showed that accumulated salts could be removed from the system thus increasing the sustainable life of the technology. This data was backed by the unplanned leaching trials that occurred when some of the sites were affected by soakage drains that became flooded and leached the salts from the system. For seven of the sites salinity did not accumulate at a rate where the leaching maintenance requirement would be uneconomic. The Sapphire site showed that where salts were added at an accelerated rate, due to the chemical toilets, that salinity quickly reached unsustainable concentrations. The required frequency of the leaching tasks would be to high for the system to be economically sustainable.

Some on-site treatment technologies can be adversely impacted by wastewater with either high or low pH. The RET system should have been resistant to dramatic pH changes due to the buffering capacity of the soil in the RET channels. The results across all eight sites confirmed this assumption with very little change in pH observed. Further long-term studies are required to determine the extent of this buffering capacity over time.

Dissolved oxygen was greatly affected by the types of venturi aeration used at each specific site. The improved venturi aeration system used at the more recent sites added more oxygen to the water than simple adsorption could have done. As oxygen is essential for the rapid breakdown of organic matter the new venturi system should improve treatment performance.

The temperature of the effluent depended on the temperature of the input wastewater and the climate at each of the eight sites. No part of the RET system appeared to have an impact on temperature.

3.4 Heavy Metals and Chlorinated Hydrocarbons

Heavy metals and chlorinated hydrocarbons can potentially be limiting factors in on-site wastewater treatment and reuse (CET 2001; Lock 1994). A limited amount of research has been undertaken in Australia in regards to the effects of heavy metals and chlorinated hydrocarbons in on-site wastewater. With its recirculatory design the RET channel system could be susceptible to toxic build-ups of heavy metals and chlorinated hydrocarbons.

Heavy metals can be present in wastewater due to a wide variety of reasons, such as natural background levels, household chemicals, industry, chemical treatment techniques, and even certain religious ceremonies (Mukerjee and Nandi 2000; N.R.C 1996). These heavy metals could, over time, alter the biochemistry in the contained system and have adverse phytotoxic impacts on the plants growing in the RET channels and the micro-ecosystem (Mittal and Ratra 2000; Salt *et al.* 1998).

An examination of the effluent in the holding tank at selected sites was undertaken to ascertain if heavy metal accumulation had occurred. Michael Linich from the Centre for Environmental Training has highlighted concerns that the relatively high concentrations of chlorine used for the disinfection of effluent in AWTS may be reacting with the organic matter in the wastewater and forming chlorinated hydrocarbons (CET 2001). Chlorinated hydrocarbons are an environmental and public health concern as they are acknowledged as potential mutagens, carcinogens, and morbidity promoters (CET 2001; Janssens *et al.* 1997). The St Lawrence recreation area had an AWTS and a RET channel system both installed. As the wastewater flowing through these systems was generated from the same source a comparison of the amount of chlorinated hydrocarbons in the effluent from each treatment system was possible.

3.4.1 Materials and Methods

The heavy metal concentrations were assessed once per year at three selected sites. The Rockhampton trial site was selected as it had a partial industrial wastewater component, the Sapphire site as a chemical toilet dump was included in the wastewater stream from the amenities block, and the St Lawrence recreation area as the amenities block had chemical toilet dump facilities in the form of a pump-out tank in which the contents did not enter the on-site wastewater treatment systems. Samples of the local potable water supply from each site were collected at the same time.

Two composite samples from the holding tank and the potable water supply totaling 500 ml each were taken. At the St Lawrence recreation area two additional 500 ml composite samples were gathered from the pump collection well of the AWTS. A set of samples from the AWTS had been collected and analysed before the RET channel system was installed at the end of January 2001. All the samples collected were used exclusively for the heavy metal analysis. Samples were stored and transported at 4°C. The analysis was conducted at the Incitec laboratories at Gibson Island, Brisbane. Samples arrived at the laboratories within 48 hours of being collected and analysis was undertaken upon the day of arrival. The concentrations of the heavy metals were measured directly in an inductively coupled plasma argon emission spectrometer using NATA accredited standard techniques (Incitec 1999). Both 500 ml samples were analysed and an average reading was recorded as the result.

Chlorinated hydrocarbon concentrations were assessed at the St Lawrence recreation area. A 1 L sample was taken from the AWTS pump well and another from the RET channel return line for non-transpired effluent. A litre of effluent was required as at least two grams of solids was required from the effluent for the analysis. The sample from the return line ensured that the effluent had passed through the RET channel at least once. The effluent was collected from the return line at the start of the pump cycle; this meant that it had been in the channel for at least three hours.

A 1 L sample was taken and analysed from the AWTS before the RET channel system was installed. Samples were not taken from the AWTS in 2002 as the method of effluent irrigation had changed eliminating the chlorine disinfection stage. The samples were transported and stored at 4^{o} C. The total solids from the samples were collected using standard techniques (Csuros and Csuros 1999). Queensland Health Scientific Services determined the amount of chlorinated hydrocarbons in the total solids using gas chromatography-mass spectrometry (GCMS).

3.4.2 Heavy metals analysis

The heavy metal concentrations in the holding tank effluent at the Rockhampton are shown in Table 3.22 The Ca concentrations were relatively high in the effluent and this may have been due to concrete and lime waste, both of which contain concentrations of calcium carbonates, entering the waste-stream. The large quantities of Mg could also be associated with the concrete and lime waste, as well as the grease components that entered from the mechanical workshop waste. Aluminium varied slightly over the course of the study but had no marked increases or decreases. Boron did not accumulate to phytotoxic concentrations, as has happened in other irrigation trials (Aucejo *et al.* 1997; Gimmler *et al.* 1998).

The concentrations of some heavy metals, specifically Ba, Cd, Cr, Cu, and Ni did not alter. This was of interest because Cu and Ni are both important plant nutrients and may need to be added as fertilizer. Fertilizer application of Fe and K may also be needed as these plant nutrients decreased over time. The remaining heavy metals showed little variation. It was expected that sodium concentration would increase with the rise in salinity at this site over time; but this did not occur. The reason for the lack of sodium accumulation is not known.

Table 3.22 Heavy metal concentration in the Rockhampton site holding tank

Heavy Metal (mg/L)	Holding Tank 2000	Holding Tank 2001	Holding Tank 2002	Holding Tank 2003	Standard Deviation of Holding Tank	Average R'ton Potable Water
Al	23.00	29.50	19.00	32.50	6.1	0.40
B	2.27	1.35	0.95	1.09	0.59	<0.10
Ba	0.1	0.1	0.1	0.1	0	<0.1
Ca	656.7	437.0	445.8	521.7	101.6	9.0
Cd	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Co	0.2	0.2	0.2	0.1	0.1	<0.1
Cr	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Cu	<0.10	<0.10	0.10	<0.10	<0.10	<0.10
Fe	15.00	12.00	6.50	5.90	4.4	<0.10
K	305.00	272.0	281.00	179.0	55	90.00
Mg	3200.0	1897.0	2284.0	1987.0	595	6.0
Mn	16.45	14.58	13.96	15.99	1.17	1.25
Na	219.0	230.0	245.0	238.0	11	64.0
Ni	0.3	0.3	0.3	0.3	0	<0.1
Pb	0.3	0.4	0.3	0.3	0.1	<0.1
Sr	0.7	0.8	0.7	0.7	0.1	<0.1
Zn	0.93	0.85	1.10	0.92	0.1	<0.10

The concentrations of heavy metals in the selected effluent types at the St Lawrence recreation area are presented in Table 3.23. There was a marked decrease in the Na concentrations in the AWTS disinfection tank between January 2001 and June 2001. It is thought that this was due to the AWTS only having a small amount of chlorine tablets present in the disinfection chamber in June 2001, while it held an almost complete load of chlorine tablets in January 2001. There was a dramatic decrease in Mg ions as in the AWTS during the same time period, however the cause of this reduction is not known.

Table 3.23 Heavy metal concentration at the St Lawrence recreation area

Heavy Metal (mg/L)	AWTS January 2001	AWTS June 2001	RET Holding Tank June 2001	RET Holding Tank February 2002	Average St Law. Potable Water 2001
Al	68.00	<0.10	<0.10	<0.10	<0.10
B	1.20	0.10	<0.10	<0.10	<0.10
Ba	0.2	0.1	<0.1	<0.1	<0.1
Ca	400.0	14.0	21.0	18.0	19.0
Cd	<0.03	<0.03	<0.03	<0.03	<0.03
Co	0.5	<0.1	<0.1	<0.1	<0.1
Cr	<0.05	<0.05	<0.05	<0.05	<0.05
Cu	<0.10	<0.10	<0.10	<0.10	<0.10
Fe	7.00	<0.10	<0.10	<0.10	<0.10
K	75.00	14.0	8.0	7.0	6.00
Mg	2000.0	36.0	6.0	5.0	5.0
Mn	8.20	0.70	<0.10	<0.10	<0.10
Na	20600.0	384.0	77.0	64.0	59.0
Ni	0.8	<0.1	<0.1	<0.1	<0.1
Pb	0.2	<0.1	<0.1	<0.1	<0.1
Sr	2.5	0.1	<0.1	<0.1	<0.1
Zn	3.40	<0.10	<0.10	<0.10	<0.10

The concentration of heavy metals in the AWTS effluent decreased over the trial, this was expected because the volume of effluent treated solely by the AWTS decreased by approximately 80%. There were no heavy metal ions concentrations that were of toxic concern in the RET holding tank effluent. Most of the heavy metals that are required plant nutrients were in low-concentrations. The addition of these plant nutrients through either a liquid or solid fertilizer may be required.

The concentration of heavy metal ions in the holding tank effluent at the Sapphire site is presented in Table 3.24.

Table 3.24 Heavy metal concentration in the Sapphire site holding tank

Heavy Metal (mg/L)	Holding Tank June 2001	Holding Tank April 2002	Standard Deviation Of Holding Tank	Average Sapphire Potable Water
Al	115.50	192.80	54.7	0.90
B	0.39	0.46	0.05	0.40
Ba	0.6	0.5	0.1	<0.1
Ca	23.7	7.60	11.4	12.0
Cd	0.18	0.25	0.07	<0.03
Co	0.3	0.7	0.3	<0.1
Cr	0.06	0.06	0	<0.05
Cu	0.20	0.30	0.1	0.10
Fe	37.90	41.50	2.5	0.25
K	325.0	450.00	88	81.00
Mg	19.6	17.8	1.3	6.0
Mn	14.58	13.96	0.44	<0.10
Na	3450.0	3950.0	353	83.0
Ni	1.6	2.6	0.7	<0.1
Pb	<0.1	<0.1	<0.1	<0.1
Sr	0.8	0.9	0.1	<0.1
Zn	0.20	0.20	0	<0.10

The concentration of Na had a dramatic increase over the course of the trial; the salinity concentration of the effluent in the Sapphire holding tank increased over the same time-period. Aluminium increased, as did Fe, K, and Ni; excluding Al, all of these heavy metals are plant nutrients and may have accumulated due to the high rate of plant death at the site. Both Na and Al can be used in water treatment chemicals and may have increased in concentration due to inputs from the chemical toilet dump. The Ca concentration decreased by over 50%; the reason for this was not known. The concentration of the other heavy metals showed little variation.

The chlorinated hydrocarbon data for the St Lawrence recreation area is presented in Table 3.25. The St Lawrence potable water had a smaller concentration of chlorinated hydrocarbons than what was commonly reported in potable water supplies for other areas (CET 2001). This may have been due to the low concentrations of chlorine used at the St Lawrence treatment plant or relatively small quantities of carbon in water. The chlorine and carbon concentrations of the potable water discussed in the CET (2001) report were not available for comparison.

Table 3.25 St Lawrence recreation area chlorinated hydrocarbons

Chemical (mg/kg)	AWTS January 2001	AWTS June 2001	RET Channel June 2001	RET Channel February 2002	St Law. Potable Water 2001
Bromochloromethane	<1	<1	<1	<1	<1
Bromodichloromethane	<1	<1	<1	<1	<1
Chlorodibromomethane	<1	<1	<1	<1	<1
Chloroform	1.3	1.6	<1	<1	<1
1,2-Dichloroethane	2.3	<1	<1	<1	<1
1,2-Dichloroethylene	1.9	<1	<1	<1	<1
Hexachloroethane	<0.5	<0.5	<0.5	<0.5	<0.5
Tetrachloroethylene	1.6	<1	<1	<1	<1
1,1,2,2-Tetrachloroethane	<1	<1	<1	<1	<1
Trichloroethylene	1.3	<1	<1	<1	<1
1,1,1-Trichloroethane	1.4	1.1	<1	<1	<1
2,4,6-Trichorophenol	1.1	1.3	<0.5	<0.5	<0.5
2,4,5-Trichorophenol	0.7	0.7	<0.5	<0.5	<0.5

There was no concern about the quality of the effluent in regards to chlorinated hydrocarbons in the RET holding tank or the St Lawrence potable water at any time during the course of this trial. The residual chlorine in the RET channel effluent may not have been in sufficient quantities to form chlorinated hydrocarbons. The soil or the aggregate layer may have absorbed any chlorinated hydrocarbons that were formed in the RET channels. In the AWTS the highest concentrations of chlorinated hydrocarbons occurred in January 2001 when the amount of chlorine in the disinfection tank was at near capacity. In June 2001 the amount of chlorinated hydrocarbons in the AWTS decreased but the volume of effluent treated by the system had decreased by 80% and the chlorine levels in the disinfection chamber was only at approximately 15% capacity. In general there was no water quality sustainability concerns in regards to heavy metals or chlorinated hydrocarbons concentrations in the holding tank effluent. The concentrations of sodium were of concern at the Sapphire site.

3.4.3 Discussion on Heavy Metals and Chlorinated Hydrocarbons

The most obvious conclusion from these experiments is that the contaminates of concern need to be present for there to be any toxic accumulations. In wastewater studies at STP's the variety of effluent sources often results in low concentrations of many toxic metals and chlorinated hydrocarbons. On-site wastewater treatment systems generally only receive wastewater from a limited number of sources. This may result in fewer heavy metals and other potential toxins being present in the wastewater. The results from the experiments showed this with many heavy metals being at relatively low concentrations and not undergoing any accumulation over time. Those heavy metals that are plant nutrients quite often declined in concentration. Heavy metals that were present in the wastewater however did accumulate, but not at unsustainable rates. Chlorinated hydrocarbons were not at concentrations of concern.

Chapter 4: Soil Data

The soil is an important component of the RET channels as it provides a transfer mechanism for the effluent and a growth media for the plants required for rhizofiltration and evapotranspiration. Long-term sustainability of the soil in the RET channels is essential for the continued successful treatment and reuse of the effluent. A comprehensive holistic analysis of the interactions that effluent irrigation imposes on the soil in the RET channels is required if sustainability is to be realistically assessed (Stevens *et al.* 2003).

Designing an on-site wastewater treatment and reuse system so that its meets the minimum requirements of the current Australian legislation does not ensure that the technology is sustainable in the long term. Current Australian codes fail to adequately address build-up of nutrient concentrations and other potentially limiting factors such as sodicity, salinity, heavy metals, and chlorinated hydrocarbons and how they may adversely interact with the soil in an effluent treatment and/or reuse area (Charles *et al.* 2001; Graaff and Patterson 2001; Graaff and Lustig 2001). The contained and recirculatory nature of the RET channel system exposes the soil component to relatively high quantities of effluent and does not allow the diffusion and leaching of potential limiting factors out of the treatment and/or reuse area (Clough *et al.* 1998; Whelan and Barrow 1984; Yates 1986).

The aim of the research in this chapter was to examine the long-term sustainable health of the soil in the RET channels. The accumulation and/or the decline of primary nutrients, secondary nutrients, micronutrients, heavy metals and chlorinated hydrocarbons have been examined. The long-term impact of the effluent irrigation on the salinity, sodicity, cation exchange capacity (CEC), and sodium% of cations (ESP) was assessed at each site. The movement of faecal microorganisms through the soil column in the RET channel was also examined. This holistic approach that encompasses the soil structure, chemistry and biology of the RET channel soil should provide a realistic determination of the system sustainability.

4.1 Nutrient Levels and pH

The soil in the RET channels was analysed to determine the concentrations of nutrients, and soil pH at the eight sites over the course of the trial. Nutrients may have been transferred from the effluent into the soil in the RET channels. This study was aimed to determine whether accumulations or deficiencies of specific nutrients occurred. If nutrients accumulated or declined plant health and microbial health could have been impaired (Csuros and Csuros 1999; Hartmann *et al*. 1988). The pH was monitored because the availability of soil nutrients to plants can be dependent on a specific pH range (Geelhoed *et al.* 1997; Rosecrance *et al.* 1996; Youssef and Chino 1991). If the soil pH were to go below 5.5 or above 8.5 some essential plant nutrients could have become unavailable to the plants that grew in the RET channels (Hopkins 1999). The organic carbon% was monitored due to its role as an indicator of soil health and because carbon is essential in the transformation cycles of some nutrients such as nitrogen (Davidsson and Leonardson 1996; Loosdrecht and Jetten 1998; Hopkins 1999). Organic carbon is also a major component of all microbial organisms and required for their growth (Davidsson and Leonardson 1996). The AZ/NZS 1547:2000 (WS/13/1 2000) in relation to soil nutrients states in section 4.1A5 Nutrient Loading Considerations that " In some cases, significant input of nutrients can irreversibly alter terrestrial ecosystems and water bodies. Regulatory authorities in certain jurisdictions will have set limitations on nutrient application rates to soil or groundwater in order to achieve local or regional environmental standards. This Standard bases design primarily on hydraulic loading."

The Queensland On-site Code is in agreement with this statement in the national standard. The AS/NZS 1547:2000 does not set any specific levels for soil nutrients and instead relies on the broad statement in section 2.4.1 that the serviceable life (or sustainability) of the system shall be a minimum of 15 years to cover any limiting factors imposed by soil nutrients (WS/13/1 2000). The soil nutrient study undertaken to examine primary nutrients, secondary nutrients, and micronutrients and to identify any possible factors that would limit the service life of the RET channels to less than 15 years.

4.1.1 Materials and Methods

The trial sites were all installed at different times, over a four-year period. While some trial sites were relatively close to one another (within 30 km) others were several hundred kilometers apart. It was not possible to import the soil that filled the eight RET systems from the same source; all trials were not conducted with exactly the same soil type. Soils that were used ranged from sandy loams to light clays. The soil imported into the channels was characterised prior to effluent application. A composite soil sample was obtained from four sections of the channel at the time of installation. It is not statistically viable to compare the soil results from different trial sites due to the many uncontrolled variables inherent in using different soil types, as well as the variations in wastewater characteristics and climate. Each site was individually assessed to determine whether the relevant codes and standards were met. As on-site systems are installed on a variety of soil types this was deemed to be within the scope of the study.

All soil analysis was performed through a NATA accredited laboratory. Soil colour was visually assessed against a Munsell colour chart and soil texture was determined with the Northcote technique (Incitec 2003). Organic carbon analysis was performed using the Walkley and Black method and determined colormetrically (Incitec 2003). The pH was determined using a 0.01 M calcium chloride method and read with a combination electrode (Incitec 2003). Potassium levels were obtained through an ammonium acetate reaction and measured on an inductively coupled plasma argon emission spectrometer (ICP AES) (Incitec 2003). Nitrate was measured colormetrically in a segmented flow analyser (Incitec 2003). Phosphorus was determined by the Cowell method and measured colormetrically in a segmented flow analyser (Incitec 2003). Calcium and magnesium levels were obtained through an ammonium acetate reaction and measured on an ICP AES (Incitec 2003).

Copper, zinc, manganese, and iron were determined using DTPA, triethanomaline and calcium chloride method and measured on ICP AES (Incitec 2003). Boron was determined using a 0.01 M calcium chloride method and measured on ICP AES (Incitec 2003). Incomplete sulfur and aluminum results were obtained from the NATA laboratory. As these were not consistently examined they will not be presented. Note that in the calculation of ESP% and CEC (section 4.2) aluminum, when present, was included in the cation count.

4.1.2 Rockhampton Site

The soil placed within the RET channels at the Rockhampton site was a dark brown fine sandy loam. The thirteen channels of the site were planted with a variety of plants. Tables 4.1 and 4.2 show soil data for two channels that were planted with *Bambusa oldhamii* (Bamboo WS and Bamboo RD), one channel with two tropical fruit trees (*Carambola* sp. and *Euphoria longan*), and one channel with banana (*Musa* sp.). These channels were chosen for examination to help determine what impact plant selection had on soil conditions within the RET channels. The bamboo species is a fast growing grass that does not regularly flower or fruit (approximately once every hundred years). The tropical fruit trees, are perennial species that flower and fruit at different times of the year (*Euphoria longan* spring-summer; *Carambola* sp. summer-autumn). The individual banana plants produce one bunch of bananas in a lifecycle (approximately 14 months) and then plant is then cut down and removed from the system and replaced by a banana-sucker. The plants in the RET channel will determine to a large extent what nutrients accumulate and which decline. As different plants have diverse nutrient requirements it is thought that nutrient concentrations will differ between the RET channels.

Table 4.1 Primary nutrients, pH and organic carbon % of RET system soil at the Rockhampton site

Soil Sample	Organic Carbon %C	Soil pH (1:5 $CaCl_2$)	Potassium meq/100g	Nitrate mg/kg	Phosphorus mg/kg
Original Soil 1998	1.7	6.3	0.15	23.2	30
Bamboo WS 2001	2.1	6.9	0.74	6.2	82
Bamboo WS 2003	2.9	7.1	0.68	8.5	88
Bamboo RD 2001	3.1	7.2	0.84	7.7	81
Bamboo RD 2003	3.3	7.2	1.12	7.8	78
Tropical Fruits 2001	1.7	7.4	0.36	19.8	33
Tropical Fruits 2003	1.5	7.9	0.29	11.1	47
Banana 2001	1.8	7.9	0.13	5.5	31
Banana 2003	1.0	7.9	0.25	3.1	25

The soil data in Table 4.1 showed differential response between plant species. Organic carbon% was higher in the pots planted with bamboo. This may have been because bamboo frequently drops its leaves and the root mass is concentrated in the top 0-50 cm leading to high levels of soil carbon (Kleinhenz and Midmore 2001). Soil in all of the pots became more alkaline over time. The soil pH remains in the preferred range. The potassium levels quickly increased in all pots except banana.

Banana fruit contains relatively high levels of potassium and over 50 banana bunches have been harvested at the site. Most probably banana plants have removed the potassium in their fruit. Soil nitrate dropped in all of the pots compared with the original soil.

Table 4.2 Secondary nutrients and micronutrients of RET system soil at the Rockhampton site

Soil Sample	Calcium meq/100g	Magnesium meq/100g	Copper mg/kg	Zinc mg/kg	Manganese mg/kg	Iron mg/kg	Boron mg/kg
Original Soil 1998	4.53	1.90	1.9	4.3	1.55	97	0.6
Bamboo WS 2001	10.81	4.11	1.9	7.1	3.40	72	0.8
Bamboo WS 2003	11.37	3.92	2.2	7.6	3.92	60	0.9
Bamboo RD 2001	13.21	3.67	2.0	3.3	1.75	92	0.9
Bamboo RD 2003	15.84	7.03	1.3	3.2	1.80	70	1.2
Tropical Fruits 2001	14.25	3.92	2.1	5.1	1.95	51	0.4
Tropical Fruits 2003	19.28	4.61	2.0	5.7	1.90	20	0.4
Banana 2001	12.01	3.90	1.3	1.2	5.13	45	0.6
Banana 2003	12.81	5.06	0.8	0.8	5.01	29	0.3

Phosphorus levels increased substantially in the bamboo pots, slightly in the tropical fruit pot, and remained relatively constant in the banana pot. No toxic accumulations of nutrients were observed when these data are compared to those of Hopkins (1999). There was an increase in calcium and magnesium in the soil in all pots (Table 4.2). These nutrients may enter the waste stream as components of industrial wastewater from the concrete manufacturing process. They have not reached toxic levels (Hopkins 1999). Copper and boron have not substantially altered in any of the pots. Zinc and iron levels have dropped in the banana pot this may be in relation to the banana fruit production. There was a sizeable difference in the zinc and manganese levels between Bamboo WS and Bamboo RD. The Bamboo WS plants appeared to be adversely affected by a prevailing wind that reduced their growth. The biomass (visual basis) of the plants in Bamboo RD was greater than in Bamboo WS as the former were sheltered from the prevailing wind. This growth difference may account for the difference in the levels of zinc and manganese. The levels of iron decreased in all pots compared to original soil.

4.1.3 St Lawrence Domestic Site

The soil placed within the RET channels at the St Lawrence domestic site was a dark grey fine sandy loam. The primary nutrients, pH and organic carbon % data for the site is presented in Table 4.3 and the secondary nutrients and micronutrients are shown in Table 4.4. At this site four RET channels were planted with *Bambusa oldhamii*. Two of these channels were in the herring-bone (HB) design and the other two in the channel-to-channel flow-through (CC) design. One type of each design was under-planted (a) with *Plumbago auriculata*, a small semi-hardy evergreen shrub that produces large quantities of sky-blue flowers in summer.

Table 4.3 Primary nutrients, pH and organic carbon % of RET system soil at the St Lawrence domestic site

Soil Sample	Organic Carbon %C	Soil pH (1:5 $CaCl_2$)	Potassium meq/100g	Nitrate mg/kg	Phosphorus mg/kg
Original Soil 1999	2.3	6.2	0.41	84.9	440
Bamboo HB (a) 2001	1.6	6.2	0.28	44.3	410
Bamboo HB (a) 2003	1.4	7.6	0.45	17.7	445
Bamboo HB (b) 2001	1.8	6.8	0.23	26.2	269
Bamboo HB (b) 2003	1.1	7.4	0.45	29.5	290
Bamboo CC (a) 2001	1.8	6.9	0.38	6.4	168
Bamboo CC (a) 2003	1.2	7.2	0.29	6.8	187
Bamboo CC (b) 2001	1.7	6.3	0.18	4.6	296
Bamboo CC (b) 2003	1.2	7.0	0.29	6.9	280
Citrus CC (a) 2001	1.3	6.5	0.35	22.9	210
Citrus CC (a) 2003	1.1	6.3	0.35	39.9	181
Citrus CC (b) 2001	1.4	6.7	0.28	16.9	280
Citrus CC (b) 2003	1.2	7.1	0.34	20.1	310

Table 4.4 Secondary nutrients and micronutrients of RET system soil at the St Lawrence domestic site

Soil Sample	Calcium meq/100g	Magnesium meq/100g	Copper mg/kg	Zinc mg/kg	Manganese mg/kg	Iron mg/kg	Boron mg/kg
Original Soil 1999	3.12	0.98	1.7	3.6	16	88	0.4
Bamboo HB (a) 2001	3.94	1.13	1.2	2.9	14	176	0.3
Bamboo HB (a) 2003	5.76	1.96	0.8	3.9	9	67	0.8
Bamboo HB (b) 2001	4.61	1.18	1.1	3.5	10	98	0.3
Bamboo HB (b) 2003	4.59	1.99	0.7	3.7	13	66	0.6
Bamboo CC (a) 2001	4.22	1.73	0.8	2.5	7	85	0.5
Bamboo CC (a) 2003	5.14	1.84	0.6	2.2	7	56	0.5
Bamboo PP (b) 2001	4.53	1.90	0.8	2.8	6	76	0.6
Bamboo CC (b) 2003	4.91	1.96	0.7	3.3	8	57	0.6
Citrus CC (a) 2001	4.11	1.97	0.9	3.1	8	82	0.8
Citrus CC (a) 2003	4.88	2.22	0.6	3.6	6	64	0.6
Citrus CC (b) 2001	5.00	2.04	1.8	2.4	8	64	0.6
Citrus CC (b) 2003	5.13	2.05	0.9	3.3	7	52	0.7

The other two channels were left with no under-storey (b) and had only *Bambusa oldhamii* growing within them. The soil of these four RET channels planted with *Bambusa oldhamii* was examined. In addition two RET channels (CC) planted with *Citrus sinensis* (oranges) were examined. The Citrus CC (a) channel was under-planted with *Passiflora edulis* (passionfruit) and the citrus CC (b) was not under-planted. The original soil from this site was purchased from Sarina, a small township involved with the sugar-cane industry. The soil had a sugar-cane by-product called bagasse added to it as organic mulch. Bagasse has a high carbon percentage and a relatively large concentration of phosphorus as seen by the 440 mg/kg in the original soil. The organic carbon% decreased in all of the selected RET channel soils. Carbon is an energy source for the microbiological oxidization of nitrogen (Li *et al.* 1998). If ammonia from the effluent had been transformed into other types of nitrogen the organic carbon% present in the original soil may have been used as an energy source (Wang and Alva 1999). Carbon can be added to effluent reuse irrigation through methane compounds present in the wastewater; however this is quite often in insufficient concentrations to replace the amount of carbon used by the microbiological transformation of nitrogen (Xie *et al.* 2003). No marked differences occurred between the under-planted and non-under planted channels in relation to organic carbon%. The soil pH gradually became more alkaline in all the selected RET channels, except in the Citrus CC (a). In this channel the soil became slightly more alkaline in 2001, but had become more acidic in 2003. The reason for this was not known. Potassium ion concentration increased in both types of HB bamboo channels by approximately the same amount. In comparison to the original soil the potassium concentration decreased in the CC bamboo channels. The bamboo channel CC (b) had a slight rise in potassium ions in 2003. In relation to the original soil the concentration of nitrate ions decreased dramatically in all of the selected RET channels. The bamboo HB (a) nitrate ion concentration continued to decrease throughout the trial whereas the bamboo HB (b) had a slight rise in nitrate ions in 2003. The nitrate ions in the bamboo CC channels reduced to the smallest concentrations. Both citrus channels had a substantial nitrate ion reduction in 2001 and smaller increase in nitrate ions in 2003. This may be due to a reduced growth rate in the channel plants in 2003 caused by an increase in the plants maturity. It is also possible with the citrus channels at the end of the CC design that excess nitrate ions from ammonia transformation in the previous channels are available.

The calcium ions increased in all the selected RET channels in relation to the original soil. Magnesium ion concentrations also increased and on average accumulated in the four years of the trial by approximately 100%, whereas copper ion concentrations fell by about the same amount during the same period. Zinc ion concentrations were relatively stable and only reduced consistently in Bamboo CC (a); it is possible that zinc is required in relatively high concentrations by the *Plumbago auriculata*. In comparison to the original soil the manganese ion concentrations decreased in all of the selected RET channels over the course of the trial. Iron concentrations fell overall during the trial, a large quantity of iron was detected in the Bamboo HB (a) 2001 sample but this may have been a nonrepresentative result. Boron increased slightly in all of the RET channels in relation to the original soil.

4.1.4 St Lawrence recreation area

The soil placed within the St Lawrence recreation area was a dark grey brown fine sandy loam. The soil data for the primary nutrients, pH and organic carbon % for the St Lawrence recreation area is presented in Table 4.5. The 2003a samples were collected in January 2003 and the 2003b samples in July 2003. The examination at this site was undertaken to determine in a channel-channel flow-through design was there a substantial difference in soil conditions between the start and the end of the channel sequence. Channel 1 had a twelve-channel sequence, and channels 2 and 3 six-channel lengths each. Organic carbon% has fallen overall with no apparent difference between the start and end of the channels. The pH levels in channel 1 and 2 were of concern. The aeration systems for these channels needed and received maintenance when the soil samples were taken. The aeration system of channel 3 was in good repair. It is thought that due to the lack of aeration the soil in channels 1 and 2 is acidic. Soil samples taken from these channels when the aeration system was working were not below pH 6.5. This site was retrofitted with a new-style venturi aeration system in late January 2002 and the old-style venturi system was removed. Potassium was in a smaller concentration at the end of each channel than it was at the start. Potassium did not accumulate within the soil at this site and was in all samples at a lower concentration than it was in the original soil sample.

Table 4.5 Primary nutrients, pH and organic carbon % of RET system soil at the St Lawrence recreation area

Soil Sample	Organic Carbon %C	Soil pH (1:5 $CaCl_2$)	Potassium meq/100g	Nitrate mg/kg	Phosphorus mg/kg
Original Soil 2001	1.4	6.8	0.31	41.8	15
Channel 1 Start 2002	1.3	7.2	0.26	27.4	17
Channel 1 End 2002	1.3	6.7	0.12	38.6	16
Channel 1 Start 2003a	1.2	5.1	0.26	6.6	12
Channel 1 End 2003a	1.1	4.9	0.12	34.3	13
Channel 1 Start 2003b	1.1	7.2	0.24	21.4	10
Channel 1 End 2003b	1.1	6.4	0.16	16.5	15
Channel 2 Start 2002	1.2	6.8	0.2	22.8	21
Channel 2 End 2002	1.2	6.5	0.12	27.9	23
Channel 2 Start 2003a	1.2	5.5	0.2	5.7	17
Channel 2 End 2003a	1.0	5.8	0.12	17.2	15
Channel 2 Start 2003b	1.0	6.9	0.19	4.2	15
Channel 2 End 2003b	1.0	6.9	0.13	21.9	8
Channel 3 Start 2002	1.4	7.4	0.24	18.9	15
Channel 3 End 2002	1.3	6.9	0.18	42.9	21
Channel 3 Start 2003a	0.9	6.6	0.24	16.9	16
Channel 3 End 2003a	1.1	6.4	0.18	32.9	18
Channel 3 Start 2003b	0.6	7.1	0.22	9.9	16
Channel 3 End 2003b	0.9	6.9	0.16	23.9	11

Nitrate ion concentrations increased at the end of each channel, except in the Channel 1 2003b results. It is thought the ammonia was microbiologically oxidized within the channels and that this made more nitrate ions available in the soil at the channel ends. Nitrate did not accumulate within the channels and in all samples, bar one, was at a reduced concentration when compared with the original soil. Phosphorus ions did not accumulate and showed no definitive pattern in regards to increases or decreases in ion concentration at the start or the end of the RET channel sequence.

The secondary nutrients and micronutrients of the RET system soil at the St Lawrence recreation ground are presented in Table 4.6. Calcium ions decreased between the start and the end of the channel sequence in channel 1, but the opposite occurred in channels 2 and 3. The reason for this difference is not known; however overall calcium ion concentrations did not increase at this site. Magnesium ions did increase in the soil at the start of channel 1 when compared with the original soil, but was at a smaller concentration in all other soil samples. Magnesium ions were consistently at a lower concentration at the end of a channel sequence. Copper ions increased within the soil at the system, except in channel 1. The copper ions approximately doubled in channel 3 and tripled in channel 2. The reason for this was not known, and no discernable pattern in regards to increases or decreases at the start or the end of a RET channel sequence was determined. Manganese and iron ions had overall increase within the soil at the site; no clear pattern in regards to these accumulations could be established.

Table 4.6 Secondary nutrients and micronutrients of RET system soil at the St Lawrence recreation area after two years

Soil Sample	Calcium meq/100g	Magnesium meq/100g	Copper mg/kg	Zinc mg/kg	Manganese mg/kg	Iron mg/kg	Boron mg/kg
Original Soil	2.40	1.83	0.4	2.7	8	43	0.9
Channel 1 Start	2.14	2.94	0.3	1.9	10	100	0.8
Channel 1 End	1.52	1.67	0.4	1.1	14	255	0.4
Channel 2 Start	3.06	1.67	1.4	2.7	31	212	0.7
Channel 2 End	4.41	1.47	1.0	1.5	8	110	0.5
Channel 3 Start	4.02	1.27	0.7	1.3	9	54	0.6
Channel 3 End	4.39	1.11	0.9	1.7	10	109	0.7

Boron ions decreased within RET system soil. Channels 1 and 2 had lower concentrations at the end of the channel sequences, whereas channel 3 had a small increase in boron ions at the end of the channel series.

4.1.5 Gem Air Site

The soil in the channels at the Gem-Air site was classified as brown light clay. At the Gem-Air Village Caravan Park the soil was examined for pH, nutrients, and organic carbon %, after it had been in the channels for one year. It was compared with results from composite samples of the original soil before it was submitted to effluent irrigation and this data is shown in Tables 4.7 and 4.8. Each of the four modified RET channels was planted in an identical manner. Four soil samples were removed from the each channel and made into one composite sample.

Table 4.7 Primary nutrients, pH and organic carbon % of RET system soil at the Gem-Air site after one year

Soil Sample	Organic Carbon %C	Soil pH (1:5 $CaCl_2$)	Potassium meq/100g	Nitrate mg/kg	Phosphorus mg/kg
Original Soil 2002	0.95	7.4	0.36	68.8	19.75
Channel 1	0.4	7.7	0.66	2.38	17
Channel 2	0.8	7.7	0.97	2.5	16.1
Channel 3	0.6	7.8	1.00	0.4	22
Channel 4	0.5	7.7	1.05	0.3	22

The organic carbon% has gone down in all 4 channels. This may be because carbon is needed in some chemical reactions, such as those in the nitrogen cycle (Cochet *et al.* 1990). As time progresses the system may need to have some organic carbon added, perhaps in the form of charcoal. The pH of the soil has become more alkaline. In all 4 channels it is still in the acceptable range for plant growth. In channel 1, potassium concentrations doubled, in the 3 remaining channels it has tripled. It has not reached toxic levels, and may decrease when the plants reach maturity and begin to flower and fruit in large quantities (Hopkins 1999). Nitrate ions have dramatically decreased in all 4 channels. Phosphorus ions have on average gone down slightly in the channels compared to the original soil. Calcium and magnesium have both increased substantially. The reason for this is not clear; the non-potable water at the site has kaolite added to it, as a settling agent and this may be the source. The cations may also come from the reuse of the effluent that has passed through the sand and zeolite filter. Zeolite can be a source of cations, through a cation exchange capacity (CEC), but whether they are leaching into the effluent from the zeolite in this case is yet to be determined.

Table 4.8 Secondary nutrients and micronutrients of RET system soil at the Gem-Air site after one year

Soil Sample	Calcium meq/100g	Magnesium meq/100g	Copper mg/kg	Zinc mg/kg	Manganese mg/kg	Iron mg/kg	Boron mg/kg
Original Soil 2002	7.71	3.34	0.6	1.4	9	38	0.6
Channel 1	33.91	15.68	0.5	<0.1	3	6	0.8
Channel 2	25.72	11.87	0.9	0.9	6	30	1.1
Channel 3	31.52	14.47	1.0	0.3	7	15	1.2
Channel 4	32.15	13.95	1.5	0.3	13	19	1.1

Copper and boron ion concentrations have on average increased but not to toxic levels. Zinc concentrations in the soil have fallen to the point where the plants may in the future suffer a zinc deficiency (Hopkins 1999). Manganese and iron levels have fallen overall but are present in high enough concentrations to ensure plant health (Hopkins 1999).

4.1.6 Sapphire Site

The soil used within the RET channels at the Sapphire was classified as brown clay loam. The nutrient data, organic carbon %, and pH readings for the Sapphire site is recorded in Tables 4.9 and 4.10. The bamboo channel was planted with three-clumps of *Bambusa oldhamii* and was in the herringbone design. The other RET channel soil selected for examination was in the channel-to-channel flow-through design and was planted with a native of central Queensland, *Melaleuca nervosa*, a small tree with a weeping canopy and abundant flowers for up to six-months of the year (Pearson and Pearson 1984).

Table 4.9 Primary nutrients, pH and organic carbon % of RET system soil at the Sapphire site

Soil Sample	Organic Carbon %C	Soil pH (1:5 $CaCl_2$)	Potassium meq/100g	Nitrate mg/kg	Phosphorus mg/kg
Original Soil 2000	1.9	6.5	0.18	34.6	67
Bamboo 2001	1.1	4.4	0.28	5.7	9
Bamboo 2002	1.1	4.3	0.27	4.2	7
Melaleuca nervosa 2001	1.3	4.3	0.27	5.2	7
Melaleuca nervosa 2002	1.0	4.2	0.27	4.4	5

The organic carbon % decreased when compared to the original soil. The soil pH became more acidic as the trial progressed; it is thought that this was due to the impact of the chemical toilet waste dump. The venturi valve aeration system was examined and found to be in working order. Potassium ions accumulated within the soil but did not reach phytotoxic concentrations. Nitrate and phosphorus ions decreased in the soil substantially when compared with the concentrations present in the original soil. The acidic conditions may have made these nutrients more biologically available to the microorganisms in the soil and the biofilms, and the plants that survived in the RET channels (Aten and Gupta 1996; Elgala and Amberger 1988).

Table 4.10 Secondary nutrients and micronutrients of RET system soil at the Sapphire site

Soil Sample	Calcium meq/100g	Magnesium meq/100g	Copper mg/kg	Zinc mg/kg	Manganese mg/kg	Iron mg/kg	Boron mg/kg
Original Soil 2000	5.14	1.54	1.2	4.4	3	118	0.4
Bamboo 2001	0.86	4.96	0.5	1.6	6	145	1.5
Bamboo 2002	0.68	4.91	0.6	1.7	3	125	1.6
Melaleuca nervosa 2001	0.69	4.79	0.6	1.7	4	143	1.6
Melaleuca nervosa 2002	0.69	4.98	0.7	1.4	2	104	1.7

The calcium ions had a marked decrease within the soil present in the RET channels; the cause of this was not known. Magnesium and boron ion concentrations both increased, but not to phytotoxic concentrations (Hopkins 1999). Copper and zinc concentrations both decreased, this may by due to the soil pH as both of these nutrients become more biologically available in acidic pH conditions (Elgala and Amberger 1988; Sauerbeck 1991). Manganese and iron ion concentrations did not alter markedly from the concentration present in the original soil.

4.1.7 Rubyvale Site

The soil in the Rubyvale RET channels was a brown clay loam. The nutrient, pH, and organic carbon % data for the soil in the selected RET channels at the Rubyvale site are presented in Tables 4.11 and 4.12. The bamboo channels were planted with three clumps of *Bambusa oldhamii* and the citrus channel with two examples of *Citrus paradisi* (grapefruit).

Table 4.11 Primary nutrients, pH and organic carbon % of RET system soil at the Rubyvale site

Soil Sample	Organic Carbon %C	Soil pH (1:5 $CaCl_2$)	Potassium meq/100g	Nitrate mg/kg	Phosphorus mg/kg
Original Soil 2000	3.4	6.3	0.37	48.0	121
Bamboo 2000	1.9	6.2	0.24	19.8	102
Bamboo 2002	0.6	6.1	0.21	8.6	108
Citrus 2000	4.0	6.1	0.57	10.5	120
Citrus 2002	1.9	6.1	0.18	34.6	101

The bamboo channel was at the start of the channel-to-channel flow-through design and the citrus at the end of the channel sequence. Over the course of the trial the organic carbon % decreased in all RET channels. The soil pH also decreased marginally when compared with the original soil but appeared to reach a stable reading. In 2000 in the citrus channel there was a increase in the potassium ion concentration, however both selected RET channels showed a decrease in potassium ions in the 2002 soil samples. Nitrate ions decreased overall when compared with the original soil. The citrus soil had an increase in nitrate ions in 2002; this was not unexpected in the soil at the end of channel sequence.

Table 4.12 Secondary nutrients and micronutrients of RET system soil at the Rubyvale site

Soil Sample	Calcium meq/100g	Magnesium meq/100g	Copper mg/kg	Zinc mg/kg	Manganese mg/kg	Iron mg/kg	Boron mg/kg
Original Soil 2000	2.71	5.96	0.7	6.8	55	141	0.9
Bamboo 2000	1.70	4.43	0.7	2.7	11	148	0.3
Bamboo 2002	0.98	3.01	0.5	1.2	15	159	0.3
Citrus 2000	8.57	2.47	1.4	4.4	28	122	0.8
Citrus 2002	5.14	1.54	1.2	2.2	3	118	0.4

There was an unusual concentration of calcium ions in the citrus RET channel length. It is not known whether the ions accumulated within the channel or if there was a substantial concentration of calcium in the soil that was placed within the citrus RET sample that was not present in the samples of soil taken to determine the nutrient ion quantities in the original soil. It does appear that calcium ions did decrease over time and did not accumulate within the soil. Magnesium and zinc ions both decreased over time; bamboo soil had the largest decrease in zinc and citrus the largest decrease in magnesium.

Boron ion concentration decreased overall and by the greatest amount in the bamboo channel. Copper ion concentration decreased in the bamboo channels, but increased within the citrus channel. The citrus may have had a copper based treatment applied to its potting soil in the nursery to prevent citrus related diseases. This may be the cause of the slight increase in copper concentrations in comparison to the original soil. Iron concentrations did not alter markedly, a slight increase occurred in the bamboo channel and a small decrease in the citrus channel.

4.1.8 Anakie Site

The RET channels in the Anakie site were filled with a brown light clay. The nutrient data, pH, and organic carbon % of the soil in the selected RET channels at the Anakie site are shown in Tables 4.13 and 4.14. The citrus channels were planted with *Citrus reticulata* (Mandarin) and the other channel selected for examination was planted with *Melaleuca nervosa*.

The organic carbon % decreased from what was present in the original soil. This reduction was only very small in the citrus channel and was much more pronounced in the *Melaleuca nervosa* channel. The soil pH became more alkaline over the course of the trial; this site treated greywater that was alkaline in nature.

Potassium and nitrate ions both decreased at this site. There was no increase in nitrate ions in the soil of the *Melaleuca nervosa* channel even though it was at the end of channel sequence. Phosphorus ion concentration in the soil increased in both of the selected channels; it had not reached phytotoxic concentrations.

Table 4.13 Primary nutrients, pH and organic carbon % of RET system soil at the Anakie site

Soil Sample	Organic Carbon %C	Soil pH (1:5 $CaCl_2$)	Potassium meq/100g	Nitrate mg/kg	Phosphorus mg/kg
Original Soil 2000	1.3	7.9	0.15	8.3	16
Citrus 2000	1.2	8.0	0.14	6.7	23
Citrus 2002	1.2	8.5	0.09	5.5	76
Melaleuca nervosa 2000	0.9	7.9	0.10	4.3	19
Melaleuca nervosa 2002	0.7	8.2	0.06	2.9	45

Table 4.14 Secondary nutrients and micronutrients of RET system soil at the Anakie site

Soil Sample	Calcium meq/100g	Magnesium meq/100g	Copper mg/kg	Zinc mg/kg	Manganese mg/kg	Iron mg/kg	Boron mg/kg
Original Soil 2000	19.09	4.00	1.6	5.9	19	112	0.9
Citrus 2000	21.08	3.92	8.9	6.1	23	107	1.1
Citrus 2002	23.75	3.83	10.2	5.9	27	111	1.3
Melaleuca nervosa 2000	20.19	2.01	2.1	5.9	28	98	0.9
Melaleuca nervosa 2002	22.00	2.07	1.9	5.7	33	76	0.9

The calcium ion concentrations in the soil at this site increased slightly in both of the selected RET channels. This may have due to the relatively high quantities of calcium ion that were present in the groundwater used at this site. Magnesium ions decreased initially in 2000 but appeared to have reached a stable concentration in 2002. The copper ions had increased dramatically in the soil of the citrus channel; the citrus plants in this channel had been drenched with a copper-oxychloride solution to treat and black-spot mould infection, and it is thought that this was the cause of the increase in copper. Copper increased slightly in the *Melaleuca nervosa* channel in the year 2000 but decreased in 2002. Zinc ion concentration remained stable in both channels, boron ions remained stable in the *Melaleuca nervosa* channel, and increased slightly in the citrus channel. Iron ions decreased a little in the citrus channel and to a greater extent in the *Melaleuca nervosa* channel. Manganese ions increased in both channels, but not to phytotoxic concentrations.

4.1.9 Yaamba Site

The soil that filled the RET channels at the Yaamba site was a dark grey brown fine sandy loam. The nutrient data, pH, and organic carbon % data for the selected RET channels at the Yaamba site are presented in Tables 4.15 and 4.16. The bamboo channel was planted with three-clumps of *Bambusa oldhamii*, the citrus channel with *Citrus limon* (Lemon), and the final channel chosen for examination was planted with *Melaleuca nervosa*. The organic carbon % remained relatively constant in the bamboo channel, but decreased in the citrus and *Melaleuca nervosa* channel. The soil pH did become more alkaline at this site; the wastewater at this site was alkaline due to the alkaline groundwater used at the site. Potassium ion concentration decreased in all of the soil samples, to the extent where potassium may need to added as a fertilizer. Nitrate and phosphorus ion concentrations both decreased in the selected RET channel soil at the Yaamba site. While the decrease in ion concentrations was consistent, there was variation between the selected RET channels in regard to the quantity that the nutrient ions decreased.

Table 4.15 Primary nutrients, pH and organic carbon % of RET system soil at the Yaamba site

Soil Sample	Organic Carbon %C	Soil pH (1:5 $CaCl_2$)	Potassium meq/100g	Nitrate mg/kg	Phosphorus mg/kg
Original Soil 1999	0.9	7.2	0.23	45.0	22
Bamboo 2001	0.8	7.4	0.21	12.4	24
Bamboo 2003	1.0	8.1	0.14	5.3	20
Citrus 2001	0.6	7.6	0.19	31.4	16
Citrus 2003	0.4	8.2	0.08	7.1	13
Melaleuca nervosa 2001	0.7	7.3	0.10	5.9	11
Melaleuca nervosa 2003	0.4	8.1	0.06	2.8	11

The calcium ions increased in the soil of the selected RET channels; this may have due to the groundwater at the site passing through mineral ore deposits that are rich in calcium. Magnesium ions accumulated slightly within the soil; it was thought that as the site was Copper ions fell slightly in the bamboo channel, and decreased dramatically in the citrus and *Melaleuca nervosa* channel. Zinc concentrations remained stable in the bamboo channel, approximately halved in the citrus channel, and decreased by about three-quarters in the *Melaleuca nervosa* channel. There was an increase in manganese ions in the bamboo channel in 2003, whereas manganese ions decreased in the other two channels. Iron and boron ion concentrations decreased in the soil of all of the selected RET channels when compared with the original soil.

Table 4.16 Secondary nutrients and micronutrients of RET system soil at the Yaamba site

Soil Sample	Calcium meq/100g	Magnesium meq/100g	Copper mg/kg	Zinc mg/kg	Manganese mg/kg	Iron mg/kg	Boron mg/kg
Original Soil 1999	12.49	4.56	2.1	4.9	6	42	1.2
Bamboo 2001	13.45	4.65	1.9	5.1	4	11	0.5
Bamboo 2003	14.21	5.60	1.7	4.1	15	13	0.5
Citrus 2001	15.48	4.82	1.2	2.9	6	8	0.3
Citrus 2003	17.27	4.92	0.4	1.8	4	7	0.2
Melaleuca nervosa 2001	13.09	5.10	0.5	0.5	7	6	0.2
Melaleuca nervosa 2003	15.27	5.67	0.4	0.2	3	6	0.2

4.2 Salinity, Sodicity, Cation Exchange Capacity and Sodium Percentage of Cations

The practice of effluent irrigation has been reported to increase the salinity and sodicity of soil in the application area (Balks *et al*. 1998; Graaff and Patterson 2001). Salinity can be defined as the total concentration of salts in a soil or water sample (Graaff and Patterson 2001). Salts in sufficient concentration may have a phytotoxic effect on plants and a detrimental impact on soil structure (Bond 1998; Graaff and Patterson 2001). Sodicity impacts soil sustainability as the physical properties of the soil, especially the clay portion, can be deteriorated through increasing sodicity adversely impacting soil permeability (Balks *et al*. 1998; Quirk and Schofield 1955). Sodicity cannot be defined by simply referring to the amount of sodium present in a soil sample.

The cation exchange capacity (CEC) must be determined. The CEC can be defined as the total negative electric charge per mass of soil (Graaff and Patterson 2001). If the CEC value is high the impact of sodium may be less, depending on the soil types and chemical properties, such as pH. If the pH is alkaline some clay soils will be more prone to the adverse effects of dispersion (Graaff and Patterson 2001). Some types of clays, such as bentonite, as well as limestone soils, and humus generally have high CEC values (Graaff and Patterson 2001). A measurement that can be used to determine the impact of sodium on soils is the exchangeable sodium percentage (ESP) (Graaff and Patterson 2001). This measurement is an effective tool in the determination of the adverse impacts of sodicity on soil structure because it indicates the amount of sodium ions that aid the dispersion of soils in relation to the amount of calcium and magnesium that help maintain soil structure through flocculation and the maintenance of colloids (Graaff and Patterson 2001).

4.2.1 Materials and Methods

The soil samples for these tests were the same samples that collected and used for the primary, secondary, and micronutrient examination. Samples were obtained from all sites and transported and stored at 4^{o}C. The Incitec laboratories on Gibson Island in Brisbane performed all analysis. Sodium was determined through an ammonium acetate reaction and measured on an ICP AES (Incitec 2003). Chloride was prepared and measured colormetrically in a segmented flow analyser (Incitec 2003). Electrical conductivity (EC) was measured with a conductivity meter. The EC of saturated extract (se) is based on conversions of EC (1:5) and soil texture class, to obtain a more meaningful determination of the soil salinity hazard (Incitec 2003).

The equation used to calculate the cation exchange capacity was:

CEC = the sum of K, Ca, Mg, Na, and Al (Incitec 2003)

The equation used to calculate the sodium% of cations was:

ESP = Na x 100/CEC (Incitec 2003)

4.2.2 Rockhampton Site

The salinity, sodicity, and CEC values of the soil in the selected RET channels at the Rockhampton site are presented in Table 4.17. The original soil would not be considered ideal for the application of effluent, due to a relatively low CEC value and a high ESP percentage. However the wastewater at this site contained substantial quantities of calcium carbonates in the form of waste concrete and lime. It can be seen in the soil samples taken from the selected RET channels that the CEC value increased and the ESP percentage decreased, this is supported by the nutrient data which showed an increase in the calcium and magnesium ions at this site. Total sodium ions in the soil at the site actually increased but other cations must have accumulated at a quicker rate. A slight decrease in sodium ions did occur in bamboo RD channel; the reason for this was not known.

Table 4.17 Salinity, sodicity, and CEC of RET system soil at the Rockhampton site

Soil Sample	Sodium meq/100g	Chloride mg/kg	EC dS/m	EC (se) dS/m	Cation Ex. Cap. meq/100g	Sodium% of Cations (ESP)
Original Soil 1998	1.99	145	0.21	2.2	8.60	23.13
Bamboo WS 2001	2.10	175	0.28	3.2	12.90	16.85
Bamboo WS 2003	2.28	205	0.35	3.6	18.23	12.48
Bamboo RD 2001	2.05	155	0.35	3.5	15.99	8.95
Bamboo RD 2003	1.80	185	0.32	3.3	25.80	6.99
Tropical Fruits 2001	2.55	210	0.45	4.4	22.55	12.46
Tropical Fruits 2003	2.76	380	0.51	5.2	26.95	10.26
Banana 2001	2.30	125	0.21	2.1	15.68	19.84
Banana 2003	3.04	100	0.24	2.5	21.16	14.35

Chloride ions increased in all of the selected RET channels except the banana. Investigations have shown that banana plants use a small amount of chloride ions as a nutrient (Hopkins 1999). In all of the selected RET channels the EC (se) increased in relation to the original soil. The tropical fruit channel had the greatest accumulation of chloride ions and salinity.

4.2.3 St Lawrence Domestic Site

The salinity, sodicity, and CEC data obtained from the soil in the selected RET channels at the St Lawrence domestic site are presented in Table 4.18. There was an initial decrease (2001 samples) in sodium ion concentrations in the soil of the bamboo channels when compared to the original soil. In the 2003 samples sodium had increased dramatically in the HB, but remained in relatively low concentrations in the CC channels. The reason for this difference was not known. Sodium concentrations in the under-planted CC citrus channel remained stable, whereas the citrus non-under-planted had about a 50% increase in sodium ions. Over the course of the trial the chloride ions increased within the bamboo HB channels, while overall decreasing within the bamboo CC channels. It is unknown why the different designs had an effect on chloride concentrations. The chloride ions had a marked increase in the citrus CC (a) channel when compared to the original soil. Chloride concentrations also increased in the citrus CC (b) channel but not to the same extent. Both citrus channels had a decrease in chloride ions in 2003 when compared to the 2001 samples. The EC (se) increased slightly in the bamboo HB (a) sample, and approximately doubled in the bamboo HB (b) over the course of the trial. In relation to the original soil, the EC (se) of the bamboo CC samples decreased by about 50%

during the four-years of the trial. The salinity of the citrus channels remained relatively stable.

Table 4.18 Salinity, sodicity, and CEC of RET system soil at the St Lawrence domestic site

Soil Sample	Sodium meq/100g	Chloride mg/kg	EC dS/m	EC (se) dS/m	Cation Ex. Cap. meq/100g	Sodium% of Cations (ESP)
Original Soil 1999	2.2	80	0.41	4.2	8.54	16.50
Bamboo HB (a) 2001	0.34	15	0.10	1.1	5.59	6.03
Bamboo HB (a) 2003	4.14	310	0.47	4.8	12.31	33.64
Bamboo HB (b) 2001	1.54	165	0.25	2.6	7.57	20.36
Bamboo HB (b) 2003	5.02	690	0.89	9.2	12.05	41.64
Bamboo CC (a) 2001	0.27	25	0.07	0.8	6.60	4.16
Bamboo CC (a) 2003	1.77	85	0.20	2.1	9.04	19.57
Bamboo CC (b) 2001	1.99	130	0.21	2.2	8.60	23.13
Bamboo CC (b) 2003	1.62	50	0.18	1.8	8.78	18.41
Citrus CC (a) 2001	2.01	330	0.52	5.1	9.09	22.47
Citrus CC (a) 2003	1.95	225	0.43	4.4	9.40	20.75
Citrus CC (b) 2001	2.98	165	0.41	4.3	9.52	30.55
Citrus CC (b) 2003	3.08	150	0.36	3.7	10.60	29.09

The CEC of soil in all of the selected RET channels increased slightly in the four years of the trial. A large increase in ESP occurred within the bamboo HB channels, while only a small rise in ESP percentage occurred in the bamboo CC channels. The citrus channels had the largest ESP values in 2001; in both channels the ESP percentages decreased slightly in 2003.

4.2.4 St Lawrence Recreation Area

The salinity, sodicity, and CEC values for the soil samples from the St Lawrence recreation area are presented in Table 4.19.

Table 4.19 Salinity, sodicity, and CEC of RET system soil at the St Lawrence recreation area after two years

Soil Sample	Sodium meq/100g	Chloride mg/kg	EC dS/m	EC (se) dS/m	Cation Ex. Cap. meq/100g	Sodium% of Cations (ESP)
Original Soil 2001	1.97	390	0.39	4.1	7.02	29.72
Channel 1 Start	0.67	120	0.12	1.2	9.81	6.83
Channel 1 End	2.58	440	0.49	4.9	7.07	36.47
Channel 2 Start	1.09	205	0.21	2.2	6.29	17.32
Channel 2 End	0.97	205	0.24	2.5	6.96	13.92
Channel 3 Start	3.4	570	0.58	6.0	8.94	38.08
Channel 3 End	1.77	350	0.37	3.8	7.44	23.72

The sodium and chloride levels in some parts of the channels have risen, while in others it has fallen. Overall the sodium and chloride levels have fallen, but only slightly. An accumulation of these two ions has not occurred. The EC and EC (se) readings also exhibit a small overall drop, and no generalized increase over the channels. The average cation exchange capacity in the channels has been slightly raised over the two-years. The ESP percentage has fallen approximately one-third. This can in part be accounted for by the small fall in sodium ions and the slight increases in calcium and magnesium ions. No pattern can be discerned between the start and the end of the channels.

4.2.5 Gem Air Site

The soil data in respect to the CEC, sodicity, and salinity of the soil in the Gem-Air caravan park are shown in Table 4.20.

Table 4.20 Salinity, sodicity, and CEC of RET system soil at the Gem Air site after 1 year

Soil Sample	Sodium meq/100g	Chloride mg/kg	EC dS/m	EC (se) dS/m	Cation Ex. Cap. meq/100g	Sodium% of Cations (ESP)
Original Soil 2002	3.08	420	0.57	5.9	14.13	23.4
Channel 1	1.41	650	1.21	8.9	51.66	2.74
Channel 2	1.15	185	0.29	2.1	39.71	2.9
Channel 3	2.2	145	0.32	2.4	49.19	4.47
Channel 4	1.94	270	0.39	2.9	49.09	3.95

The original soil values indicate that this soil was not an optimum blend to use in effluent application area. However the soil improved over the course of the trial. The sodium levels in the soil have fallen; it is thought that ions may have leached out and passed into the next treatment stage. The chloride levels, EC and EC (se) in channel 1 are of concern, but overall the amount of chloride ions and the EC readings in the channel soil have decreased. The CEC has increased and the ESP decreased, this is most likely due to the large increases in calcium and magnesium, as shown by the soil nutrient data. The ESP percentages indicate that the effluent application to the soil is at sustainable quantities.

4.2.6 Sapphire site

The salinity, sodicity, and CEC data for the soil in the selected RET channels at the Sapphire site are presented in Table 4.21.

Table 4.21 Salinity, sodicity, and CEC of RET system soil at the Sapphire site

Soil Sample	Sodium meq/100g	Chloride mg/kg	EC dS/m	EC (se) dS/m	Cation Ex. Cap. meq/100g	Sodium% of Cations (ESP)
Original Soil 2000	0.55	45	0.13	1.5	7.45	7.42
Citrus 2001	8.62	2150	1.44	10.6	15.54	55.47
Citrus 2002	10.30	2500	1.64	12.2	17.18	59.97
Melaleuca nervosa 2001	9.64	2200	1.51	11.2	16.39	58.80
Melaleuca nervosa 2002	10.99	2650	1.79	13.2	18.04	60.92

The original soil was suitable for the application of effluent with relatively low salinity concentrations and low ESP values. An application of a mulch/humus through the original soil would have increased the CEC and produced an even more sustainable soil for effluent application. The sodium and chloride ions, as well as the EC (se), increased dramatically at this site. There was no substantial difference between the various RET channels in regards to these increases. The CEC of the soil increased by approximately 60%, but during the same-period the ESP increased by about eight-fold. The effluent added to this soil was at unsustainable quantities and the sodium and chloride ions present in the wastewater were at concentrations that would adversely affect the soil structure.

4.2.7 Rubyvale site

For the soil in the selected RET channels at the Rubyvale site the salinity, sodicity, and CEC data was presented in Table 4.22. Overall the sodium and the chloride ions decreased in the RET channels when compared with the original soil.

Table 4.22 Salinity, sodicity, and CEC of RET system soil at the Rubyvale site

Soil Sample	Sodium meq/100 g	Chloride mg/kg	EC dS/m	EC (se) dS/m	Cation Ex. Cap. meq/100 g	Sodium% of Cations (ESP)
Original Soil 2000	0.80	100	0.13	1.3	10.42	7.65
Bamboo 2000	0.79	45	0.10	1.2	7.42	10.61
Bamboo 2002	0.74	45	0.08	0.9	6.03	12.29
Citrus 2000	0.65	50	0.30	2.7	12.26	5.29
Citrus 2002	0.66	45	0.13	1.5	7.45	7.42

The EC (se) values decreased overall in the bamboo channel, and increased slightly in the citrus channel. The CEC values in the bamboo channel decreased; the soil nutrient data showed that calcium ions decreased dramatically in this channel. The ESP percentage in the bamboo channel increased slightly. The opposite occurred in the citrus channels, where the calcium ions increased in this soil, a small increase in the CEC happened in the year 2000 sample and a decrease was recorded in the ESP percentage. In 2002 the citrus soil had a decrease in calcium and magnesium ions in comparison to the 2000 soil sample. The 2002 citrus soil CEC decreased and the ESP percentage increased. At no stage did CEC or ESP values in these soil samples reach unsustainable readings.

4.2.8 Anakie site

The results from the soil examination in the selected RET channels for salinity, sodicity, and CEC at the Anakie site are shown in Table 4.23. The sodium ions decreased in the citrus channel and increased by a small amount in the *Melaleuca nervosa* channel.

Table 4.23 Salinity, sodicity, and CEC of RET system soil at the Anakie site

Soil Sample	Sodium meq/100g	Chloride mg/kg	EC dS/m	EC (se) dS/m	Cation Ex. Cap. meq/100g	Sodium% of Cations (ESP)
Original Soil 2000	2.05	310	0.49	4.6	25.10	8.00
Citrus 2000	2.3	300	0.54	6.3	19.7	12.00
Citrus 2002	1.4	470	0.74	7.6	9.7	14.00
Melaleuca nervosa 2000	1.7	500	1.3	13.4	13.4	13.00
Melaleuca nervosa 2002	2.2	280	0.41	4.2	11.8	19.00

The chloride ion concentration increased in the citrus concentration and decreased slightly in the *Melaleuca nervosa* channel when compared with the original soil. There was a small increase in salinity (EC se) in the citrus soil samples; whereas the *Melaleuca nervosa* had a large increase in the year 2000 sample only to have a substantial decrease in the 2002 sample to bring it below the original soil value. The CEC values declined in both of the selected RET channels over the course of the study, while the ESP increased.

4.2.9 Yaamba Site

The salinity, sodicity, and CEC data for the soil samples taken from the Yaamba site are presented in Table 4.24

Table 4.24 Salinity, sodicity, and CEC of RET system soil at the Yaamba site

Soil Sample	Sodium meq/100g	Chloride mg/kg	EC dS/m	EC (se) dS/m	Cation Ex. Cap. meq/100g	Sodium% of Cations (ESP)
Original Soil 1999	0.65	50	0.30	2.7	22.26	5.29
Bamboo 2001	0.89	53	0.32	2.7	22.19	6.10
Bamboo 2003	1.99	75	0.22	2.2	22.99	8.65
Citrus 2001	3.20	219	0.52	5.1	25.84	19.37
Citrus 2003	5.87	340	0.63	6.5	25.81	22.72
Melaleuca nervosa 2001	1.89	220	0.47	4.9	22.92	8.42
Melaleuca nervosa 2003	2.09	330	0.53	5.5	24.36	8.59

The sodium and chloride ions increased in the soil samples taken from both RET channels. The EC (se) decreased slightly in the bamboo channel, but rose by at least 50% in the other two channels. The CEC remained constant in the bamboo channel, and increased by a small amount in the citrus and *Melaleuca nervosa* channels. The ESP percentages increased by about 50% in the bamboo and *Melaleuca nervosa* channels but had a marked rise of approximately 400% in the citrus channel. The soil nutrient data did not show a substantial reduction in either the calcium or magnesium ion concentrations to account for this result.

4.3 Soil Microorganisms

Soil provides a suitable environment for a large quantity of microorganisms from all the major microbial groups, such as, bacteria, fungi, algae, protista, and viruses (Csuros and Csuros 1999). Microorganisms are required in the soil for the decomposition of organic matter to produce biologically available nutrients that can be used by plants. The numbers and the types of microorganisms change frequently within the soil, as the physical and chemical environment of the soil is highly variable in relation to aeration, moisture levels, temperature, organic content, and physical structure (Csuros and Csuros 1999; Vervoort *et al.* 1999; Vries 1972). The soil can also perform an important treatment task in on-site wastewater treatment and reuse (Vries 1972). Soil is often described as a filter for wastewater, removing potential pathogens and nutrient (Jayawardane and Blackwell 1996). The soil can be a hostile environment to the potential pathogens that are present in effluent; the soil may not be right temperature or have sufficient moisture, and the soil microorganisms quite often out-compete wastewater borne microorganisms for resources (Gerba *et al.* 1975; Miller and Wolf 1975; Rahe *et al.* 1978; Straub *et al.* 1993). Not all microorganisms are removed through soil filtration and it is possible for certain types of potential pathogen to survive and replicate in some soils, as reported in Byappanahalli and Fujioka (1998) and Fujioka *et al.* (1999). It was not known whether the soil within the RET channels would act as a treatment filter or provide a suitable environment for the certain potential pathogens to survive and replicate; hence the investigation undertaken into the microorganisms and RET channel soil.

4.3.1 Material and Methods

The soil microorganism study was preformed at four sites, these being the Rockhampton, St Lawrence recreation area, Anakie, and Yaamba. Composite soil samples were taken from the RET channels. Three channels were randomly selected for sampling. A soil corer was used to take soil from two depths in the RET channels, 10 cm and 30 cm from the top of the channel mound. At 30 cm depth the soil was saturated with effluent, at 10 cm the soil was relatively dry. Approximately 50 g of soil were collected from each sample. At each site the three soil samples from the same depth were mixed into one composite sample. Each site was tested twice; the same three channels randomly selected for the first test were used in the second experimental run. At the St Lawrence recreation area the soil along the irrigation line from the AWTS was tested prior and after the installation of the RET channel. Surface soil adjacent to the irrigation drippers of the AWTS irrigation line was collected. Three soil samples of approximately 50 g each was collected and analysed, the results averaged and presented as one sample.

The soil samples were stored and transported at 4^{o} C. The Public Health Microbiology Department of Queensland Health Scientific Services carried out the microorganism determination. The samples were received by the laboratory within 24 hours of them being taken.

No technique has been uniformly accepted as a standard in regards to enumerating soil organisms (Csuros and Csuros 1999). Queensland Health Scientific Services prepared the soil samples for dilution by the following method as described in Csuros and Csuros (1999):

1. For each sample, make a dilution blank containing 95 ml of phosphate buffer diluent and use 15 to 20 two mm glass beads. Also, make separately 7 dilution blanks with the diluent, each one containing 90 ml
2. Cap the bottles and autoclave at 121^{o} C for 20 min
3. Transfer 10 g of moist soil sample to the bottle containing the 95 ml of diluent and the two mm glass beads
4. Cap the bottle, place on mechanical shaker, and shake for 10 min
5. After removing the sample from the shaker and just before using, shake the bottle vigorously

6. Immediately thereafter, transfer 10 ml of the soil suspension taken from the centre of the suspension to a fresh 90 ml blank. This establishes the 10^{-2} dilution.
7. Cap and vigorously shake this bottle, and remove 10 ml of the suspension as previously described. Continue the sequence until the 10^{-7} is reached.

The dilution series were used to determine; heterotrophic colony forming units per g at 37^{o}C/48 hrs according to the method described in (AS(a) 2000), total coliforms most probable number (MPN)/g using the method described in (AS(b) 2000), faecal coliforms MPN/g according to the method described in (AS(c) 2000), and faecal streptococci MPN/g using the method described in (AS(d) 2000). The soil microbiology test reports were all NATA accredited. Faecal coliforms are distinct from total coliforms because faecal coliforms are thermotolerant and can be incubated at 44.5 °C and produce colonies (Csuros and Csuros 1999; Tchobanoglous and Burton 1991).

4.3.2 Results of soil microorganism study

The microorganism soil data for the Rockhampton site is presented in Table 4.25. There was little variation in the number of heterotrophic organisms colonies formed per gram in relation to soil depth. In all three types of potential pathogens the higher soil samples (10 cm) had dramatically reduced numbers of microorganisms. The greatest reduction occurred in total coliform numbers.

Table 4.25 Soil microorganisms at the Rockhampton site

Sample	Heterotrophic CFU/g	Total Coliforms MPN/g	Faecal Coliforms MPN/g	Faecal Streptococci MPN/g
Rockhampton 10 cm 2001	3.9×10^9	90	20	23
Rockhampton 30 cm 2001	1.85×10^7	150 000	69 000	12 000
Rockhampton 10 cm 2002	8.1×10^8	110	60	<1
Rockhampton 30 cm 2002	7.8×10^7	160 000	52 000	7000

The 30 cm soil samples were in direct contact with the effluent at the bottom of the RET channel and it is thought that this why the numbers of potential pathogens were higher.

The soil microorganisms results at the St Lawrence recreation area for the AWTS irrigation line and the RET channel soil are presented in Table 4.26. The first AWTS samples were taken before the RET system was installed and the second six-months after the RET installation. There was no marked difference in heterotrophic organisms between the two AWTS samples. There was a substantial reduction with the AWTS soil in 2001 in regards to total coliforms and faecal coliforms. This was most likely due to the reduced volume of effluent (approx. 80%) that was passing through the AWTS unit after the RET system had been installed. Faecal streptococci numbers also decreased but only by about 50%, it is possible that the soil conditions suited these organisms more than what occurred with the other potential pathogens. Within the RET channels the there was the greatest number of potential pathogens at the 30 cm depth in both years. Most of the coliforms that produced colonies appeared to be faecal in origin.

Table 4.26 Soil microorganisms at the St Lawrence recreation area

Sample	Heterotrophic CFU/g	Total Coliforms MPN/g	Faecal Coliforms MPN/g	Faecal Streptococci MPN/g
AWTS Soil 2000	1.153×10^8	72 100	26 760	4 460
AWTS Soil 2001	1.2×10^7	5 300	4 100	2 500
RET Channel 10 cm 2001	3.6×10^7	500	450	<1
RET Channel 30 cm 2001	4.9×10^6	75 000	56 000	112
RET Channel 10 cm 2002	4.1×10^7	450	120	<1
RET Channel 30 cm 2002	8.2×10^6	60 000	54 000	83

Relatively few faecal streptococci were found within the RET channels, it is possible that the conditions within the RET channels were unfavourable for this species. The AWTS results show that faecal streptococci were present in the effluent.

The microorganisms present in the soil samples from the Anakie site are presented in Table 4.27. In both years the soil at the 30 cm depth had a two log-reduction in heterotrophic organisms compared to the 10 cm soil sample; the reason for this was not known. In 2001 at the 30 cm depth approximately half of the coliforms were faecal in origin, however in 2002 this had changed to about three-quarters. The reason for this increase in faecal coliforms within the greywater was not known.

Table 4.27 Soil microorganisms at the Anakie retirement home

Sample	Heterotrophic CFU/g	Total Coliforms MPN/g	Faecal Coliforms MPN/g	Faecal Streptococci MPN/g
Anakie 10 cm 2001	4.8×10^8	45	5	85
Anakie 30 cm 2001	3.2×10^6	60 000	32 000	15 000
Anakie 10 cm 2002	4.3×10^8	50	5	130
Anakie 30 cm 2002	2.6×10^6	45 000	36 000	17 000

The 10 cm soil samples showed a marked reduction in potential pathogen numbers in both years when compared to the 30 cm soil samples. Faecal coliforms underwent the greatest reduction in numbers, followed by the total coliforms, and then the faecal streptococci.

The soil microorganism data for the Yaamba site is shown in Table 4.28. There was a two-log reduction in heterotrophic organisms between the two soil depths, with the 10 cm sample having the highest population in both years. The vast predominance of coliform species appeared to be faecal in origin in both years. The coliforms that survived in the 10 cm soil sample had a relatively small number of faecal species; this may indicate that the environmental conditions in 10 cm soil sample were unfavourable for faecal coliforms, or that faecal coliforms were not easily transported through the soil column to the upper layers. Faecal streptococci numbers dramatically decreased in both years from the numbers recorded at the 30 cm depth when compared to the 10 cm samples. The soil at the 10 cm depth did not appear to be support the growth of faecal streptococci.

Table 4.28 Soil microorganisms at the Yaamba site

Sample	Heterotrophic CFU/g	Total Coliforms MPN/g	Faecal Coliforms MPN/g	Faecal Streptococci MPN/g
Yaamba 10 cm 2001	1.9×10^8	125	9	<1
Yaamba 30 cm 2001	2.8×10^6	13 000	12 400	1100
Yaamba 10 cm 2002	3.5×10^8	75	5	<1
Yaamba 30 cm 2002	2.7×10^6	9000	8000	800

4.4 Heavy Metal Accumulation and Chlorinated Hydrocarbons

Heavy metals can accumulate within soils when effluent is used for irrigation (Siebe 1995). If specific heavy metals accumulate to certain concentrations they can have phytotoxic effects and cause public health problems (Downs *et al.* 2000; Youssef and Chino 1991; Zalidis *et al.* 1999). Chlorinated hydrocarbons form in the soil when chlorine compounds react with organic carbon (CET 2001). Chlorinated hydrocarbons can cause harm to the environment and public health (CET 2001).

4.4.1 Material and Methods

Three sites were selected for soil heavy metal analysis, Rockhampton, St Lawrence recreation area, and Sapphire. These are the same sites that underwent effluent heavy metal examination. At each site a sample of the original soil was analysed for heavy metal concentrations before any effluent application occurred. Three RET channels were randomly selected for soil sample collection. A 25 mm diameter soil corer was used to remove a 40 cm long core from each randomly selected channel.

All of the samples were transported and stored at 4^{o}C. The analysis was conducted at the Incitec laboratories at Gibson Island. The Ba, Cd, Co, Cr, Ni, Pb, and Sr determinations were all obtained by diethylenetriamine pentaacetic acid (DTPA) extraction (Incitec 2003). The concentrations of the other heavy metals were measured directly in an inductively coupled plasma argon emission spectrometer using NATA accredited standard techniques (Incitec 2003).

At the St Lawrence recreation area soil samples were collected from the AWTS irrigation line and the RET channels for chlorinated hydrocarbon analysis. Three sample collections occurred, one prior to the RET system being commissioned, and two after it had become functional. A third sample analysis of the AWTS irrigation run did not occur as the method of irrigation had changed from surface drip with chlorine disinfection to sub-surface drip without chlorination in mid 2002. It was thought that the change in irrigation technique would produce incomparable results especially in regards to the production of chlorinated hydrocarbons. A 25 mm soil corer was used to take three soil cores, 15 cm long from the AWTS irrigation line. These samples were mixed to form a composite sample. A 25 mm soil corer was used to take 40 cm soil cores from one randomly selected RET channel in each of the three irrigation runs at the site. These samples were mixed and used to form one composite sample.

The samples were stored and transported at 4°C. Queensland Health Scientific Services determined the amount of chlorinated hydrocarbons in the soil sample composites using gas chromatography-mass spectrometry (GCMS).

4.4.2 Soil heavy metal concentrations

The concentration of heavy metal ions in the RET channel soil at the Rockhampton site are presented in Table 4.29.

Table 4.29 Soil heavy metal concentration at the Rockhampton site

Heavy Metal	Original Soil 1998 (mg/Kg)	RET Channel Soil 2000 (mg/Kg)	RET Channel Soil 2003 (mg/Kg)
B	0.6	0.7	0.8
Ba	<0.1	0.4	0.6
Ca	4.53	13.52	14.93
Cd	<0.03	0.03	0.03
Co	0.2	0.3	03
Cr	<0.05	<0.05	<0.05
Cu	1.9	2.1	2.2
Fe	97	75	69
K	0.15	0.68	0.39
Mg	1.90	4.02	5.95
Mn	2	2	2
Ni	0.4	0.2	0.2
Pb	0.3	0.6	0.6
Sr	0.1	1.0	1.7
Zn	4.3	4.9	5.2

The K ions increased in the 2000 sample but decreased in the 2003 sample; this may be due to plant maturity requiring elevated concentrations of K for flowering and fruiting. The concentrations of the plant nutrients Ni and Fe both decreased. The concentrations of heavy metal ions for Cd, Co, Cr, and Mn were stable throughout the trial. There was a small increase in the concentrations of B, Ba, Cu, Pb, and Zn.

The heavy metals Mg, and Sr had a substantial increase in ion quantities. There was a marked increase in the concentration of calcium ions at the site.

The heavy metal concentrations for the soil in the RET channels at the St Lawrence recreation area is shown in Table 4.30.

Table 4.30 Soil heavy metal concentration at the St Lawrence recreation area

Heavy Metal	Original Soil 2000 (mg/Kg)	RET Channel Soil 2001 (mg/Kg)	RET Channel Soil 2003 (mg/Kg)
B	0.9	0.7	0.4
Ba	<0.1	0.7	0.8
Ca	2.52	3.06	4.12
Cd	0.03	0.04	0.06
Co	0.1	0.3	0.3
Cr	<0.05	<0.05	0.07
Cu	0.4	0.7	0.8
Fe	44	210	225
K	0.34	0.24	0.16
Mg	1.94	1.67	1.27
Mn	8	12	18
Ni	0.3	0.2	0.2
Pb	2.1	1.9	2.0
Sr	0.5	0.8	0.9
Zn	2.8	1.9	2.2

The heavy metals B, K, Mg, Ni, and Zn, are all plant nutrients and all decreased in concentration in the Ret channel soil at this site. The concentrations of Pb remained stable. There was a small increase in number of ions of Cd, Co, Cr, Cu, and Sr. There was a slightly larger average increase in the ion concentration of Ba, Ca, and Mn. There was a large increase in Fe concentrations within the RET channel soil; this increase was not apparent in the nutrient data for this site.

The soil heavy metal concentration data for the Sapphire site is reported in Table 4.31. There was a decrease in the concentrations of Ca, Cu, and Zn. This was consistent with the nutrient data that reported similar decreases over a slightly shorter time period. There was a small rise in the number of ions in relation to Fe and K.

Table 4.31 Soil heavy metal concentration at the Sapphire site

Heavy Metal	Original Soil 2000 (mg/Kg)	RET Channel Soil 2001 (mg/Kg)	RET Channel Soil 2002 (mg/Kg)
B	0.4	1.9	2.1
Ba	0.4	3.0	4.1
Ca	5.25	0.9	0.7
Cd	<0.03	0.12	0.23
Co	0.2	0.5	0.9
Cr	0.09	0.28	0.43
Cu	1.1	0.6	0.6
Fe	121	145	142
K	0.18	0.27	0.28
Mg	1.54	4.89	6.1
Mn	3.0	5.0	6.0
Ni	0.2	0.8	1.9
Pb	0.4	2.7	4.9
Sr	0.7	6.7	8.9
Zn	4.3	1.6	1.4

The concentrations of B, Cd, Co, Cr, Mg, Mn, and Ni all increased. There were marked increases in the concentrations of Ba and Pb. No heavy metals remained at stable concentrations at this site.

4.4.3 Soil chlorinated hydrocarbons

The soil tests for chlorinated hydrocarbons at the St Lawrence recreation area are reported in Table 4.32.

Table 4.32 Soil chlorinated hydrocarbon concentrations at the St Lawrence recreation area

Chemical (mg/kg)	AWTS Soil January 2001	AWTS Soil June 2001	Original RET Channel Soil	RET Channel June 2001	RET Channel February 2002
Bromochloromethane	<1	<1	<1	<1	<1
Bromodichloromethane	<1	<1	<1	<1	<1
Chlorodibromomethane	<1	<1	<1	<1	<1
Chloroform	1.6	1.4	<1	<1	<1
1,2-Dichloroethane	1.9	1.1	<1	<1	<1
1,2-Dichloroethylene	1.7	<1	<1	<1	<1
Hexachloroethane	<0.5	<0.5	<0.5	<0.5	<0.5
Tetrachloroethylene	<1	<1	<1	<1	<1
1,1,2,2-Tetrachloroethane	<1	<1	<1	<1	<1
Trichloroethylene	<1	<1	<1	<1	<1
1,1,1-Trichloroethane	1.6	1.9	<1	<1	<1
2,4,6-Trichorophenol	0.9	0.9	<0.5	<0.5	<0.5
2,4,5-Trichorophenol	0.5	0.5	<0.5	<0.5	<0.5

The RET channel soil recorded no concentrations of chlorinated hydrocarbons that were of concern. The soil in the AWTS irrigation line had slightly higher concentrations of chlorinated hydrocarbons present in the soil in the January 2001 samples prior to the installation of the RET system. No chlorinated hydrocarbons were present in concentrations in the AWTS soil at levels that would be of environmental or public health concern (CET 2001).

Chapter 5: Plants

5.1 Species Selection

In the RET channel design the plants were expected to use the nutrients for growth and reuse the effluent through transpiration. The species of plants chosen for the RET channels was important as different types of plants have diverse nutrient and water requirements (Hopkins 1999). It was important to select plants that required relatively large volumes of water and nutrients, for example drought-tolerant plants that use very little water would be of limited benefit within a channel length.

Species of plants may have varying amounts of biological activity during different parts of the year. Plants commonly use large quantities of nutrients and water when flowering and fruiting and producing new growth (Hopkins 1999). Many species of plants also undergo a period of senescence, similar to hibernation in some animals, where the plant has very limited biological activity, and thus uses little water and nutrients. The plant selection process aimed to choose a variety of plants that reproduced and produced new growth at different times of the year. Through this procedure it is unlikely that all of the plants within the RET channel would be in senescence at the same time.

A monoculture was not considered appropriate for the RET channels as water and nutrient reuse quantities can vary greatly within a year. Monocultures can also be more susceptible to diseases and the toxic accumulations of limiting factors within the effluent (Hopkins 1999; Myers and Falkiner 1999). Investigations were undertaken at local nurseries to determine what plants were available for use within the trial. Certain plants were not considered for use; such as those with large invasive taproots, trees that grow greater than seven metres, Australian natives sensitive to phosphorus, and running types of bamboo.

Clumping varieties of bamboo was selected for use in the trial because it grew quickly and used relatively large quantities of water and nitrogen (Kleinhenz and Midmore 2001). Figures 5.1 and 5.2 show how quickly the bamboo grew at the St Lawrence domestic site. The bamboo in Figure 5.1 is planted at the start of the channel just after the venturi air system; this bamboo in Figure 5.2 has grown up to five metres in height in one –year.

Figure 5.1 Bamboo just after planting at the St Lawrence domestic site

Figure 5.2 Bamboo one-year after planting at the St Lawrence domestic site

The majority of bamboo species only flower and fruit very rarely. However bamboo does have a large leaf area for transpiration and biomass for nutrient use. Bamboo clumps can be cutback and reduced if size becomes a problem. Fruit-trees were selected for the trial as they may have elevated nutrient and water requirements. Fruit was also required for a microbiological study on potential pathogens (Section 5.4). A limited amount of exotic ornamental plants were chosen for the trial. Endemic Australian natives were selected and obtained from local Landcare groups. These plants were important as they were suited to the climate, supported local flora biodiversity and encouraged local fauna. A mixture of these broad types of plants was selected for most sites.

In Tables 5.1 and 5.2 the plants in channel-to-channel flow-through design channels and the herringbone channels at the Rockhampton site are shown.

Table 5.1 Plants in the channel-to-channel flow-through design channels at the Rockhampton site

RET Channel	Plant Species	Common names	New Growth Period	Reproduction Period
1	*Duranta erecta*	Duranta	Year-round	Year-round
	N/A	Christian Dior Rose	Spring	Winter-Spring
2	*Citrus limon*	Lemon	Spring	Autumn
3	*Strelitzia reginae*	Bird of Paradise	Spring	Summer-Autumn
	Phoenix reclinata	N/A	Year-round	Winter
	Nerium oleander	Oleander	Winter	Year-round
	Carica papaya	Papaw	Year-round	Year-round
4	*Musa* sp.	Banana	N/A	Year-round
5	*Grevilla rosmarinifolia*	Grevilla Gem	Year-round	Year-round

At the St Lawrence domestic site there was 24-RET channels split into four, six-sequence irrigation runs, two of a herringbone design and tow of a channel-to-channel flow-through design. Each six-sequence channel run was planted with identical top-storey plants. Top storey plants were those that were expected to grow the largest canopy (see Table 5.3). One six-channel sequence of each design was planted with an under-storey comprised of small shrubs and vines (see Table 5.4).

Table 5.2 Plants in the herringbone design channels at the Rockhampton site

RET Channel	Plant Species	Common names	New Growth Period	Reproduction Period
1	*Bambusa oldhamii*	N/A	Spring-Summer	N/A
2	*Bambusa oldhamii*	N/A	Spring-Summer	N/A
3	*Carambola* sp. *Euphoria longan*	Five-corner Fruit Longan	Spring Winter	Summer-Autumn Spring-Summer
4	*Heliconia brasiliensis*	Crab-claw	Year-round	Winter
5	*Citrus sinensis*	Orange	Spring	Autumn
6	Dictyosperma album	Princess Palm	Year-round	Year-round
	Macadamia ternifolia	Macadamia Nut	Autumn	Late Winter-Summer
7	*Callistemon citrinus*	Bottle Brush	Year-round	Spring and Autumn
	Deplanchea tetraphylla	Golden Bouquet Tree	Spring	Summer
8	*Thuja occidentalis*	Book-leaf Pine	Summer	Winter

Table 5.3 Top-storey Plants in each six RET channel sequence at the St Lawrence domestic site

RET Channel	Plant Species	Common names	New Growth Period	Reproduction Period
1	*Bambusa oldhamii*	N/A	Spring-Summer	N/A
2	*Melaleuca nervosa*	Ti-tree	Late Summer	Autumn-Winter
	Carica papaya	Papaw	Year-round	Year-round
3	Salacca edulis	Salak	Summer	Winter-Autumn
	Syzygium samarangense	Water Roseapple	Spring	Late Summer-Autumn
4	Malpighia punicifolia	Barbados Cherry	Late Winter-Spring	Autumn-Winter
	Myrciaria cauliflora	Jaboticaba	Autumn	Spring – Early Autumn
5	*Manilkara zapota*	Sapodilla	Summer	Winter
	Macadamia ternifolia	Macadamia Nut	Autumn	Late Winter-Summer
6	*Citrus sinensis*	Orange	Spring	Autumn

Table 5.4 Under-storey plants in the selected six-sequence RET channels at the St Lawrence domestic site

RET Channel	Plant Species	Common names	New Growth Period	Reproduction Period
1	*Plumbago auriculata*	Plumbago	Spring	Year-round
2	*Gardenia augusta*	Gardenia	Summer	Winter
	Hibiscus rosa-sinensis	Hibiscus	Winter	Spring
3	*Duranta plumieri*	Duranta	Year-round	Year-round
4	*Syzgium australe*	Syzgium	Summer	Winter
5	*Vitis* sp.	Grape	Spring	Summer-Autumn
6	*Passiflora edulis*	Passion-fruit	Year-round	Year-round

At the St Lawrence recreation area there was 24-RET channels installed. Twelve of these RET channels were planted with bamboo and the other twelve with non-bamboo species. Six species of bamboo were selected for the trial; individual channels were planted with two clumps of each a single bamboo species. There were three channel sequences installed, two with six channels each and the last with twelve. One six-channel sequence was planted with bamboo; the other six-channel sequence was planted with non-bamboo species. The twelve-sequence channel lengths was planted with the exact species used in the two-six channel lengths, that is six bamboo species channels and six non-bamboo species channels (see Figure 5.4 and 5.5)

Table 5.5 Bamboo species at the St Lawrence recreation area

RET Channel	Plant Species	Common names	New Growth Period	Reproduction Period
1	*Bambusa oldhamii*	N/A	Spring-Summer	N/A
2	*Bambusa arnhemica*	N/A	Spring-Summer	N/A
3	*Bambusa multiplex*	N/A	Spring-Summer	N/A
4	*Bambusa vulgaris*	Bar-code Bamboo	Spring-Summer	N/A
5	*Dendrocalamus brandsii*	N/A	Spring-Summer	N/A
6	*Bambusa lako*	Timor Black	Spring-Summer	N/A

Table 5.6 Non-bamboo species planted at the St Lawrence recreation area

RET Channel	Plant Species	Common names	New Growth Period	Reproduction Period
1	*Melaleuca nervosa*	Ti-tree	Late Summer	Autumn-Winter
	Syzygium samarangense	Water Roseapple	Spring	Late Summer-Autumn
2	*Callistemon citrinus*	Bottle Brush	Year-round	Spring and Autumn
	Malpighia punicifolia	Barbados Cherry	Late Winter-Spring	Autumn-Winter
3	Spondias mombin	Hog-plum	Year-round	Spring
	Punica granatum	Pomegranate	Spring	Summer
4	*Manilkara zapota*	Sapodilla	Summer	Winter
	Macadamia ternifolia	Macadamia Nut	Autumn	Late Winter-Summer
5	*Citrus limon*	Lemon	Spring	Autumn
	Acacia podalryifolia	Mount Morgan Wattle	Spring	Autumn-Winter
6	*Thuja occidentalis*	Book-leaf Pine	Summer	Winter
	Pyrostegia venusta	Orange Trumpet Vine	Year-Round	Year-Round
	Jasminum Sambac	Tropic Jasmine Vine	Year-Round	Winter

At the Gem-Air caravan park the RET channels were modified. This resulted in four channels that were approximately twelve metres in length. The four modified channels were planted in an identical manner. Ten plants were selected for use in each channel and they were planted in the same order in each channel (see Table 5.7).

Table 5.7 The order in which the ten selected plant species were planted in the modified RET channels at the Gem-Air site.

Planting Order in Channel	Plant Species	Common names	New Growth Period	Reproduction Period
1	*Melaleuca nervosa*	Ti-tree	Late Summer	Autumn-Winter
2	*Morus nigra*	Mulberry	Spring	Summer
3	*Grevilla rosmarinifolia*	Grevilla Gem	Year-round	Year-round
4	*Persea americana*	Avocado	Winter	Spring-Summer
5	*Melaleuca fulgens*	N/A	Year-round	Year-round
6	*Citrus limon*	Lemon	Spring	Autumn
7	*Callistemon citrinus*	Bottle Brush	Year-round	Spring and Autumn
8	*Eriobotrya japonica*	Loquat	Spring	Autumn
9	*Melaleuca hypericifolia*	N/A	Autumn	Winter-Spring
10	*Manilkara zapota*	Sapodilla	Summer	Winter

There was eight RET channels at the Sapphire site, four in the herringbone design and four in the channel-to-channel flow-through design. Each four-channel sequence was planted with the same plants (see Table 5.8).

Table 5.8 The plants in the Sapphire site RET channels

RET Channel	Plant Species	Common names	New Growth Period	Reproduction Period
1	Bambusa oldhamii	N/A	Spring-Summer	N/A
2	*Melaleuca nervosa*	Ti-tree	Late Summer	Autumn-Winter
	Carica papaya	Papaw	Year-round	Year-round
3	*Diospyros digyna*	Chocolate Pudding Fruit	Summer	Winter
	Passiflora edulis	Passion-fruit	Year-round	Year-round
4	Salacca edulis	Salak	Summer	Winter-Autumn
	Syzygium samarangense	Water Roseapple	Spring	Late Summer-Autumn

The Rubyvale site was an eight-channel installation in the channel-to-channel flow-through design. The plant in each of the eight channels is listed in Table 5.9.

Table 5.9 The plants in the Rubyvale site RET channels

RET Channel	Plant Species	Common names	New Growth Period	Reproduction Period
1	*Bambusa oldhamii*	N/A	Spring-Summer	N/A
2	*Melaleuca nervosa*	Ti-tree	Late Summer	Autumn-Winter
	Carica papaya	Papaw	Year-round	Year-round
3	*Acacia podalryifolia*	Mount Morgan Wattle	Spring	Autumn-Winter
	Syzygium samarangense	Water Roseapple	Spring	Late Summer-Autumn
4	Malpighia punicifolia	Barbados Cherry	Late Winter-Spring	Autumn-Winter
	Eugenia brasiliensis	Grumichama	Autumn	Spring
5	*Manilkara zapota*	Sapodilla	Summer	Winter
	Melaleuca fulgens	N/A	Year-round	Year-round
6	Inga edulis	Ice-cream Bean	Autumn	Summer
	Baccaurea motleyana	Rambi	Summer	Winter
7	Rollinia deliciosa	Rollina	Spring	Summer
	Myoporum insulare	Boobialla	Year-round	Late Winter-Spring

The site at the Anakie retirement home was comprised of seven-channels in the channel-to-channel flow-through design, the plants in each of the channels is listed in Table 5.10.

Table 5.10 The plants in the Anakie trial site RET channels

RET Channel	Plant Species	Common names	New Growth Period	Reproduction Period
1	*Chrysopyhllum cainito*	Star-apple	Spring	Mid-Late Winter
	Monstera delicicosa	Monstera	Summer	Summer
2	*Melaleuca nervosa*	Ti-tree	Late Summer	Autumn-Winter
	Carica papaya	Papaw	Year-round	Year-round
3	*Acacia podalryifolia*	Mount Morgan Wattle	Spring	Autumn-Winter
	Syzygium samarangense	Water Roseapple	Spring	Late Summer-Autumn
4	Malpighia punicifolia	Barbados Cherry	Late Winter-Spring	Autumn-Winter
	Eugenia brasiliensis	Grumichama	Autumn	Spring
5	*Manilkara zapota*	Sapodilla	Summer	Winter
	Melaleuca fulgens	N/A	Year-round	Year-round
6	*Spondias mombin*	Hog-plum	Year-round	Spring
	Punica granatum	Pomegranate	Spring	Summer
	Passiflora edulis	Passion-fruit	Year-round	Year-round
7	*Citrus paradisi*	Orange	Spring	Autumn
	Vitis sp	Grape	Spring	Summer-Autumn

The plants that were put into each of the eight RET channels at the Yaamba site are listed in Table 5.11.

Table 5.11 The plants in the Yaamba trial site RET channels

RET Channel	Plant Species	Common names	New Growth Period	Reproduction Period
1	*Bambusa oldhamii*	N/A	Spring-Summer	N/A
2	*Melaleuca nervosa*	Ti-tree	Late Summer	Autumn-Winter
	Carica papaya	Papaw	Year-round	Year-round
3	*Carambola* sp.	Five-corner Fruit	Spring	Summer-Autumn
	Euphoria longan	Longan	Winter	Spring-Summer
4	*Morus nigra*	Mulberry	Spring	Summer
	Passiflora edulis	Passion-fruit	Year-round	Year-round
5	*Citrus limo*	Lemon	Spring	Autumn
	Eugenia brasiliensis	Grumichama	Autumn	Spring
6	*Carambola* sp.	Five-corner Fruit	Spring	Summer-Autumn
	Euphoria longan	Longan	Winter	Spring-Summer
7	*Callistemon citrinus*	Bottle Brush	Year-round	Spring and Autumn
	Malpighia punicifolia	Barbados Cherry	Late Winter-Spring	Autumn-Winter
8	*Melaleuca hypericifolia*	N/A	Autumn	Winter-Spring

5.2 Water Reuse and Transpiration Rate

All plants require and use water for the processes involved in homeostasis and transpiration. However plants do not utilize the same amount of water for these operations. Plant water usage rates differ both within and between species and are dependent on a combination of external and plant-specific physiological and morphophysiological factors (Atwell *et al.* 1999; Hopkins 1999).

Homeostatic mechanisms have two major functions, both of which are essential for the health and ultimately the life of the plant (Hopkins 1999). First of all they maintain the constancy of the internal environment of the plant. This is illustrated by the fact that most plants are comprised of approximately 90% water (Hartmann *et al*. 1988). Secondly they preserve the equilibrium between the plant and the external environment (Hopkins 1999). While the use of water in homeostasis is vital to the plant it equates to only a tiny proportion of the plants total water uptake. Transpirational processes use the vast majority of water that plants uptake (Atwell *et al*. 1999).

Transpiration is defined as the escape of water from the plant through vaporization (Atwell *et al*. 1999). Water vapor loss by transpiration can occur via three main pathways: lenticel transpiration, cuticular transpiration, and stomatal transpiration (Hopkins 1999). Lenticels are small apertures in the bark of young stems, branches and twigs through which water vapor may be lost from the plant. Lenticel transpiration accounts for 10% of the water loss from the plant (Hopkins 1999). The majority of transpiration occurs in the leaves through the cuticle and dominantly the stomata when open. The leaf cuticle is a layer of hydrophobic hydroxylated fatty acid waxy material coating the outer cell wall of most epidermal cells (Hopkins 1999). One of the primary aims of the cuticle is to stop the unregulated escape of water vapor. However at best the cuticle is only 90-95% effective, allowing a similar amount of water vapor loss as to that which occurs through the lenticels (Atwell *et al*. 1999).

The stomata are small pores that allow the regulated loss of water vapor from the leaf (Atwell *et al*. 1999). The regulation occurs primarily through the operation of guard cells either side of a stoma that allows the size of the aperture to be varied. Stomatal transpiration is responsible for approximately 80% of the water loss from the plant and uses around 75% of all water uptake by the plant (Hartmann *et al*. 1988). Transpiration rates vary greatly within and between species and, therefore, so does the water usage rate. Vascular plants will transpire between 100 and 1000 g of water for every gram of dry mass produced (Hartmann *et al*. 1988). This point shows that large amounts of water are needed for dry matter production in plants. An array of internal and external, environmental and physiological factors influences these water usage rates (Atwell *et al*. 1999).

One of the major factors influencing transpiration rate is the availability of water; this is generally not a limiting factor in wastewater reuse situations. The legislation requires that all treated effluent must be either reused or disposed of in a safe and environmentally sustainable manner within the setback distances of the property (WS/13/1 2000). To achieve these legislative requirements, old treatment system technologies like septic tanks have been increased in volume. Likewise reuse and disposal sites now require larger surface areas (WS/13/1 2000).

Evapotranspiration trenches reuse treated effluent through the biological process of plant transpiration and dispose of treated effluent through the physical method of evaporation (McGrath *et al*. 1991). Legislation requires absolute minimal subsurface or surface runoff from evapotranspiration trenches. Many factors influence the amount of treated effluent that can be reused or disposed of from an evapotranspiration trench and/or trenches. These factors include plant species, canopy architecture, plant development, plant health, climate factors, daily weather factors, soil factors, irrigation method, depth of irrigation, effluent characteristics, and specific site details (Allen *et al*. 1998; McGrath *et al*. 1991; Rogers *et al*. 1983).

These factors mean that there can be large fluctuations over time in regards to the amount of effluent that evapotranspiration trenches can reuse and dispose of safely. Treatment chambers can be designed to treat a certain volume of wastewater per hour. It is much more difficult to design an evapotranspiration trench/channel to reuse and/or dispose of a set volume of effluent an hour. Doubling the size of an evapotranspiration trench does not mean that the capacity to reuse and/or dispose of a set volume of effluent has in itself been doubled (Allen *et al*. 1998).

Evaporation and transpiration are two distinct processes. Conditions that are ideal for evaporation may not be ideal for transpiration and vice versa (Allen *et al*. 1998). Transpiration and evaporation though distinct processes do operate simultaneously under most conditions (Allen *et al*. 1998). In an evapotranspiration trench effluent reuse and/or disposal per hour can be described as a ratio between transpiration and evaporation. This ratio between evaporation and transpiration effluent use is constantly varying as the multitude of factors that influence evapotranspiration change. Evapotranspiration trenches/channels need to be designed so that the processes of evaporation and transpiration can safely reuse and/or dispose of the expected daily flow of effluent from the site.

5.2.1 Materials and methods of water reuse trial

During the course of the trial it was not possible to establish the evapotranspiration rate of any particular channel sequence length at any specific time. The number of factors, such as the different species, canopy developments, soil moisture, plant health, made such a calculation impossible. Individual plants could be assessed at anyone time but long-term analysis of a single plant was not practical and would not give an evapotranspiration rate for a RET channel sequence that was accurate. To establish whether the RET channel systems were of sufficient size to reuse the treated effluent through evapotranspiration; a water meter study in conjunction with the high-water alarm in the holding tank was conducted at each site.

The amount of water used at each site was monitored through water meters on the reticulated water line. This was possible at all sites except Yaamba, which only had rainwater tanks and groundwater for water supply. In each holding tank, except at Gem-Air, a high water alarm was fitted which was triggered when effluent entered the emergency overflow. The Gem-Air site was different because excess effluent did not accumulate within the holding tank but was transferred to other treatment technologies. The householders or maintenance personnel for each site recorded each time the high-water alarm was triggered and logged a probable cause for the high-water event. To minimise the risk of missing a high-water event the alarm was designed so that once it was triggered it required resetting before it ceased the audible warnings and flashing red light. It is acknowledged that some high-water events may have gone un-recorded at each site. It was not possible to determine the amount of effluent that was disposed off in the emergency overflow. The water meter readings at each site were logged at every site visit. For each site a daily average reading for each year was calculated and recorded. It was not possible to determine what percentage of the water that went through the water-meters actually entered the liquid-waste stream. This was due to potable use within the dwellings for drinking and cooking, spillage, as well as outdoor use such as garden irrigation and car washing. This would have varied both within and between sites depending on the wastewater generation patterns. The water meter reading was used, as it was real-figure, while an estimate percentage was dependent on the same wastewater generation patterns being maintained over the course of the trial. It was not possible to determine exactly how much effluent was transpired by the plants in the RET channels at the Gem-Air site.

5.2.2 Results of water reuse trial

The results of the water-use and high-water alarms at the Rockhampton site are presented in Table 5.12. The water-meter at this site only recorded the water used in the amenities block and wash-down area. The cause of the high water alarms fell into three-categories, wet weather events, hydraulic surges, and infrastructure failure. The size of the holding tank at this site was relatively small (approximately

1000 L) and it was not resistant to hydraulic surges or the accumulation of effluent in periods of extended wet weather. In total there were five high-water alarms recorded caused by hydraulic surges from excess wastewater production in the factory, eight alarms in relation to extended periods of wet weather, and one alarm due to an infrastructure failure (toilet float failure).

Table 5.12 Water-use and high-water alarms at the Rockhampton site

Year	Average Daily Water Meter reading (litres)	Number of High-water Alarms
1999	2147	5
2000	1864	3
2001	1209	3
2002	1345	3

In 1999 there was about 783 655 L of water used at this site; the maximum estimate of effluent disposed through the emergency soakage drain in this year was 10 000 L. This is less than 1% of the total water used at the site. The vast majority of the effluent was reused in the RET channels by the plants through evapotranspiration.

The St Lawrence domestic site water meter readings and high-water alarms are recorded in Table 5.13. There was little difference in the water-use figures from year-to-year. The high water alarms were caused by four different events; emergency soakage drain flooding, hydraulic surges, human-error, and extended wet-weather events. During the trial taps were left running twice within two of he houses in the cluster. The first occasion in the year 2000 added approximately 8000 L of water into the system (left on for about nine hours); on the second occasion the tap was left partially on for a weekend (2002); an estimate was not able to be calculated but it is thought to have added over 10 000 L of water.

Table 5.13 Water-use and high-water alarms at the St Lawrence domestic site

Year	Average Daily Water Meter reading (litres)	Number of High-water Alarms
2000	4128	6
2001	3908	7
2002	4425	4

The emergency soakage drain was flooded and back-filled the holding tank seven times, mainly in 2000 and 2001. The diversion banks installed on the soakage drain in late 2002 appeared to fix the problem. There were two extended wet weather events; where the rainfall was not intense enough to flood the soakage drain but the poor evapotranspiration conditions resulted in the disposal of excess effluent in the emergency soakage drain. A small hydraulic surge in relation to clothes washing was reported on six occasions. The four houses at the site were all owned by the council and used to provide dwellings to senior employees. It was observed that when one household engaged in our major clothes and bed-linen washing event the occupants of the other three houses occasionally decided to hold a major washing event themselves. In one instance this involved eleven loads of washing done between the four houses in five hours. This practice resulted in a hydraulic surge that triggered the high-water alarm. The communal washing of clothes was not a planned event between the households; it just occurred every-so-often. The design of on-site treatment units for cluster houses should take into account these types of human instigated events.

The St Lawrence recreation area average daily water usage figures and number of high water alarms are described in Table 5.14. The high-water alarm in the holding tank was set just above the overflow into the AWTS system; it was triggered when the AWTS and RET holding tank were both filled with effluent. The horse sports events each January triggered a high water alarm. Two of the other high-water alarms were caused by human-error in leaving showers running for extended periods. No particular reason could be identified in relation to the other three-high water alarms. All three occurred in the tourist season (cooler months) and were most likely due to hydraulic surges caused by high occupancy.

Table 5.14 Water-use and high-water alarms at the St Lawrence recreation area

Year	Average Daily Water Meter reading (litres)	Number of High-water Alarms
2001	16546	3
2002	21980	4

The water-use volumes and high water alarms at the Sapphire site are shown in Table 5.15. Even though the number of plants at this site had been reduced due to poor soil conditions; the emergency soakage drain was rarely used to dispose excess effluent.

Table 5.15 Water-use and high-water alarms at the Sapphire site

Year	Average Daily Water Meter reading (litres)	Number of High-water Alarms
2000	2346	1
2001	1956	1
2002	2045	1

The three high water alarms were all caused by the same event; a market that was held each August in a public park next door to the amenities block. The market was held every Gem-festival and involved several thousand people.

The water-use values and the high-water alarms for the Rubyvale site are recorded in Table 5.16. A urinal that continually stuck in a partial flush mode caused all four high-water alarms in the year 2000. This urinal was replaced in late 2000. The average water-use figures decreased after the urinal had been replaced. The high-water alarms in the year 2001 were both caused by hydraulic surges caused by large social functions (a 21st birthday and a wedding). The cause of the 2001 high-water alarm was not determined.

Table 5.16 Water-use and high-water alarms at the Rubyvale site

Year	Average Daily Water Meter reading (litres)	Number of High-water Alarms
2000	5142	4
2001	3458	2
2002	3504	1

The Anakie water-use volumes and high-water alarm events are recorded in Table 5.17. The water-use figures were relatively constant. It was observed that all four high-water alarm events occurred during periods when the occupants of the retirement home were receiving care from health and cleaning services. The retirement home was relatively isolated and not in close contact with health care providers. It was observed that visiting nurses, cleaners, and meal providers often arrived together. The activities undertaken by these health-workers included assisting with showers, clothes washing, and house cleaning. The combination of these activities occurring in the six units within a relatively short period of time occasionally resulted in a small hydraulic surge that triggered the high-water alarm.

Table 5.17 Water-use and high-water alarms at the Anakie site

Year	Average Daily Water Meter reading (litres)	Number of High-water Alarms
2000	4590	2
2001	4379	1
2002	3984	1

The high-water alarm results from the Yaamba site are reported in Table 5.18.

Table 5.18 Water-use and high-water alarms at the Yaamba site

Year	Average Daily Water Meter reading (litres)	Number of High-water Alarms
2000	Not available	3
2001	Not available	4
2002	Not available	2

All nine high-water alarm events occurred to due stormwater movement over the Yaamba flood-plain infiltrating the emergency soakage drain and back-filling the holding tank. It was observed that relatively little wastewater was generated at the house as the occupants were very water-efficient. The holding tank was rarely above half-full under normal operating conditions and the adverse impacts of the back filling of the holding tank did not last past two days after any of the wet-weather events.

5.3 Plant Health

The good health of the plants in the RET channels was essential for nutrient reuse and the evapotranspiration of the effluent. The health of the plants at each site was monitored and any ill effects were recorded. For the RET system to be sustainable the plants in the channels need to survive, and prosper, in the long-term. Plant health will not be discussed site-by-site but according to specific factors.

5.3.1 Transplant deaths

When plants are transplanted into new environments deaths may occur (Hopkins 1999). It is thought that these deaths may be related to shock or physical damage to the plant that could have occurred during the planting process. The number of plant deaths at each site is recorded in Table 5.19.

Table 5.19 Transplant deaths at the eight trial sites

Site	Number of Transplanting Deaths
Rockhampton	0
St Lawrence domestic site	1
St Lawrence recreation area	3
Gem-Air caravan park	0
Sapphire	0
Rubyvale	2
Anakie	0
Yaamba	1

The number of plant transplant deaths was not thought to be of concern. Any plants that did die were replaced with the same species within three-months of the RET system installation.

5.3.2 Large-fauna damage

There was a small amount of damage from grazing mammals at three sites, St Lawrence recreation area, St Lawrence domestic site, and the Sapphire site. Neither St Lawrence site was fenced and it was observed that kangaroos and wallabies both selectively grazed upon plants in the RET channels. The two plant species that were selected for grazing by the marsupials were *Passiflora edulis* (passion-fruit) and

Bambusa oldhamii. The grazing did not kill members of either plant species but did reduce the leaf-area; particularly in the passion-fruit (see Figures 5.3 and 5.4).

Figure 5.3 Passion-fruit before grazing by marsupials

Figure 5.4 Passion-fruit after grazing by marsupials

It is thought that the marsupials came into town and grazed on the plants in the RET channels because of the drought conditions in their normal environment. Grazing only occurred during extended periods of low-rainfall.

A large 1.75 metre fence surrounded the Sapphire site at the Gem-Fields. This fence was constructed due to the large numbers of cattle, horses, and goats that graze, unchecked by property boundary fences, throughout the Sapphire fossicking area. Grazing still occurred at this site at random intervals. The trial had been underway for two-years before it was observed that feral camels could reach over the fence and graze the plants growing in the RET channels. The camels grazed any plant that they could reach from the fence-line. The camels reduced the leaf-matter and broke some branches but are not directly responsible for any plant deaths.

5.3.3 Insect damage

The vast majority of plants in the RET channels at all eight sites at some stage during the course of the trial were damaged by insect attack. Insects attack plants to obtain food and habitats (Hopkins 1999). The majority of the damage caused by the insects was not observed to cause long-term harm to the plants in the RET channels. Some plants did die primarily due to damage caused by insects. Citrus borers are insects that drill holes into the trunk and the branches of citrus trees. These insects can cause substantial damage; and may result in the death of a plant (Hopkins 1999). This occurred in relation to two-citrus trees at the Rockhampton site and one-tree each at the St Lawrence sites (see Table 5.20). At the St Lawrence domestic site a *Hibiscus rosa-sinensis* was adversely impacted grasshopper herbivory and died. The Anakie site lost a grapevine due to damage caused by caterpillars.

Table 5.20 Plant deaths directly related to insect damage at the eight sites

Site	Number of Insect Related Deaths
Rockhampton	2
St Lawrence domestic site	2
St Lawrence recreation area	1
Gem-Air caravan park	0
Sapphire	0
Rubyvale	0
Anakie	1
Yaamba	0

The numbers of plants lost to insect damage was not excessive and the plants were replaced as per the maintenance program. The maintenance program also involved insect infestations being identified and the affected plants sprayed with the appropriate chemicals.

5.3.4 Plant disease

For specific plant species, disease had a major impact on the RET system trial. All of the *Carica papaya* (Papaw) planted at the trial sites died of paw-paw dieback, a disease that is often fatal. Paw-paw dieback is common in central Queensland, and it is not easy to treat. The *Persea americans* (Avocado) species is vulnerable to fungal diseases that attack the roots. An avocado died at the Rockhampton and Gem-Air from a fungal root disease. Many other plants contracted disease throughout the course of the trial, the citrus species frequently were infected with black spot moulds; however no other plant deaths could be attributed to disease. If a plant was noted to have a disease, attempts were made to classify the disease and find a treatment. This was part of the maintenance cycle.

5.2.5 Adverse impacts on plants caused by the RET channels

The Sapphire site was the only RET system where it was determined that adverse impacts from effluent irrigation had resulted in plant deaths. Just over 70% of the plants within the RET channels died; all of them exhibiting toxicity effects caused by salinity (see Figure 5.5).

Figure 5.5 Bamboo at Sapphire Site after phytotoxic accumulation in soil

Not all plants died within the channels; the *Melaleuca nervosa* and *Diospyros digyna* (Chocolate pudding fruit) plants survived; the plants did show some effects of phytotoxicity, such as browning around the leaf edges, the plants did continue to transpire and use nutrients. The long-term survival of these plants at this site is expected.

5.4 Fruit Microbiology

There is a public health concern with treated effluent being used for crop irrigation (Atherton 1998). The RET system ensures that no treated effluent comes into contact with the aboveground portions of the plants. Israel has conducted many tests and trials using sub-surface effluent irrigation for crops and in the majority of cases has found it to be safe (Shuval 1991; Shuval 2003). At the Rockhampton site fruit grown in the RET channels was examined for the presence of potential pathogens.

5.4.1 Materials and Methods

Several different techniques were used to examine the fruit, both externally and internally, from the Rockhampton wastewater site for potential pathogens. Specimens of mature fruit from two citrus trees growing in the Rockhampton wastewater reuse site were chosen for examination. Four citrus trees are being grown at the Rockhampton site but only two had mature fruit at the time of the experiment. The mature fruit came from a Washington navel orange tree and a Meyer lemon tree. The trunks of the two trees were 2.5 m apart, and both trees were protected from the prevailing wind by a combination of buildings and vegetation windbreaks.

As a comparison, mature citrus fruits from two Washington navel orange trees growing in the horticulture section of the Plant Science Group compound at CQU, as well as randomly selected mature orange and lemon fruits from a local fruit and vegetable supplier were also tested. The fruit taken from CQU were grown with no wastewater irrigation. The fruit taken from the commercial situation were grown in northern New South Wales under non-wastewater irrigation.

The tests were conducted twice, on two different sets of mature citrus fruit. Only mature citrus fruit were considered suitable for this experiment. Full-grown fruit should be approximately the same age and have encountered similar environmental conditions. The two environmental conditions considered most important were the weather and insect damage. The first set of fruit was collected on the 14/4/01, and the second on the 19/4/01. Tests were conducted at this time due to the availability of suitable fruit.

All of the samples of fruit underwent two distinct forms of testing; the external environment, that is, the skin of the fruit and by an extracted juice sample. The selected fruit were collected on the same day within an hour of each other. The fruit samples taken directly by the examiner from fruit trees (Rockhampton site and University samples), the fruit were cut from the trees using a pruning knife that had been dipped in 70% ethanol and gloved hands handled the fruit. New gloves were used for each fruit, and the pruning knife was dipped into the ethanol each time before use. The samples from the fruit and vegetable supplier were handled with gloved hands, with the gloves being changed between fruit.

Each fruit was placed into an individual airtight sealed sterile plastic bag. No fruit were allowed to come into contact with other fruit. The fruit were stored and transported in an insulated cool-box at a temperature of 4°C. In the laboratory the fruit were handled using the aseptic technique described in Csuros and Csuros (1999). To take samples off the surface of each citrus fruit a 5 cm^2 sterile template was placed on the fruit. An Arrow Scientific sponge, wet with a sterile surfactant was used to swab the surface. The wet sponge was placed in a stomacher bag and appropriately pummeled to provide the microbial samples. The technique recommended by Arrow Scientific was followed (Scientific 1997). After the surface samples had been taken from the fruit they were washed twice with a 70% ethanol solution. A knife that had been washed with 70% ethanol was then used to cut the fruit in half. A Bunsen burner set on low flame and situated within the lamina flow unit was used to remove ethanol residue from the blade of the knife. The half of the fruit was then squeezed for juice. A dilution series down to 10^{-4} was conducted with a 1 ml sample of the juice. For the analysis Arrow Scientific petrifilm^{tm} was used according to the method depicted in Scientific (1997). The pour plate techniques previously described in section 2.2.1 for Chromocult and non-fastidious heterotrophic counts were also used.

5.4.2 Fruit Microbiology Results

The external examination of the citrus fruit (Table 5.21) showed that the surface of all the fruit samples contained microorganisms.

Table 5.21 Colony forming units from the fruit surface samples

Sample	Non-Fastidious Heterotrophic Petrifilm per 1 mL	Non-Fastidious Heterotrophic Pour Plate per 1 mL	[a]CEK per 100 mL	*E. coli* per 100 mL	*Salmonella* spp. per 100 mL
Site Fruit Run 1	3802	3783	117	<1	<1
Site Fruit Run 2	1100	1117	<1	<1	<1
CQU Fruit Run 1	2300	7225	10	3	<1
CQU Fruit Run 2	3200	15000	<1	<1	<1
Retail Fruit Run 1	16675	15748	1150	286	32
Retail Fruit Run 2	11606	14216	144	<1	<1

The faecal coliforms found on the surface of the fruit may indicate human faecal contamination, but they also could have originated from environmental sources. Very few faecal coliforms were found on the surface of the trial site and CQU grown fruit. Higher numbers were found on the commercially grown fruit. It is thought that these faecal coliforms may have come from being handled by the staff and consumers at the retail outlet. Poor personal hygiene can result in people transferring faecal coliforms to objects that they touch (Haas 1983).

The fruit juice samples (Table 5.22) showed much lower concentrations of microorganisms.

Table 5.22 Colony forming units from the extracted fruit juice samples

Sample	Non-Fastidious Heterotrophic Petrifilm per 1mL	Non-Fastidious Heterotrophic Pour Plate per 1mL	[a]CEK per 100mL	*E. coli* per 100mL	*Salmonella* spp. per 100mL
Site Fruit Run 1	1	1	<1	<1	<1
Site Fruit Run 2	1	<1	<1	<1	<1
CQU Fruit Run 1	2	<1	<1	<1	<1
CQU Fruit Run 2	<1	<1	<1	<1	<1
Retail Fruit Run 1	194	498	9	<1	<1
Retail Fruit Run 2	<1	1	<1	<1	<1

The barrier caused by the skin of the fruit appeared to keep most microbes out of the interior of the fruit. Skin of the fruit from the trial site and CQU had some signs of insect attack, and the commercially grown fruit appeared to have some handling damage. The fruit that was grown in the RET system had lower numbers of faecal coliforms both internally and externally than the fruit commercially sourced.

Chapter 6: Infrastructure Changes

6.1 Introduction

Over the course of the trial the RET infrastructure was assessed on its performance. The characteristics noted were durability, maintenance requirements, clogging, and resistance to non-authorised human interference. The relevant code states that an on-site wastewater treatment and reuse system, excluding the electrical components, must have a minimum life expectancy of fifteen years (WS/13/1 2000). No problems were noted with the tanks, degradation of the physical structure of the channels, or the electrical components of the trial systems. During the experiment several infrastructure changes were identified that are expected to be of benefit to the RET system. These infrastructure changes have the aims of increasing durability, and minimising clogging, maintenance requirements and non-authorised human interference.

6.2 Aeration and Effluent Distribution

A Venturi valve system was used to aerate the effluent as it entered the channel (Figure 6.1). The Venturi valves were constructed of PVC and had a 400 mm long, 20 mm diameter perforated PVC pipe as an air-intake mechanism. If multiple runs of RET channel were installed at the site a tap was installed directly before the Venturi valve to regulate the amount of effluent each irrigation run received. Problems occurred with the taps due to non-authorised human interference. Members of the public upon occasion altered the settings of the taps causing some channels to receive relatively high amounts of effluent and others a quite restricted volume. The alteration of the taps adversely affected the performance of the Venturi valves as effluent was not be pumped through the aeration system in the desired pressure range. If the volume of effluent passing though the Venturi valve was too high the pressure sometimes forced it out the air-intake pipe, causing a potential public and environmental health risk. On two occasions during the course of the experiment foreign objects blocked the intake of the Venturi valve (Rockhampton and Anakie trial sites). This caused high water levels within the holding tank. It was also noted at the St Lawrence Domestic, Anakie, Rubyvale, and Yaamba sites that insects built nests in the perforations of the 20 mm diameter PVC air-intake pipe.

Figure 6.1 Original Venturi valve

The aeration and effluent distribution system were improved by minor infrastructure changes. The Venturi valve was moved to inside the holding tank. The air-intake pipe goes through the holding tank lid. The aeration system is now designed so that approximately half of the aerated effluent is immediately discharged back into the holding tank. This reduces the risk of foreign object blockage and it is designed so that the pressure never reaches the required level for aboveground discharge through the air-vent pipe. This eliminates the potential environmental and public health risk. The additional benefit to this design is that both the effluent entering the RET channels and in the holding tank have relatively higher levels of oxygen.

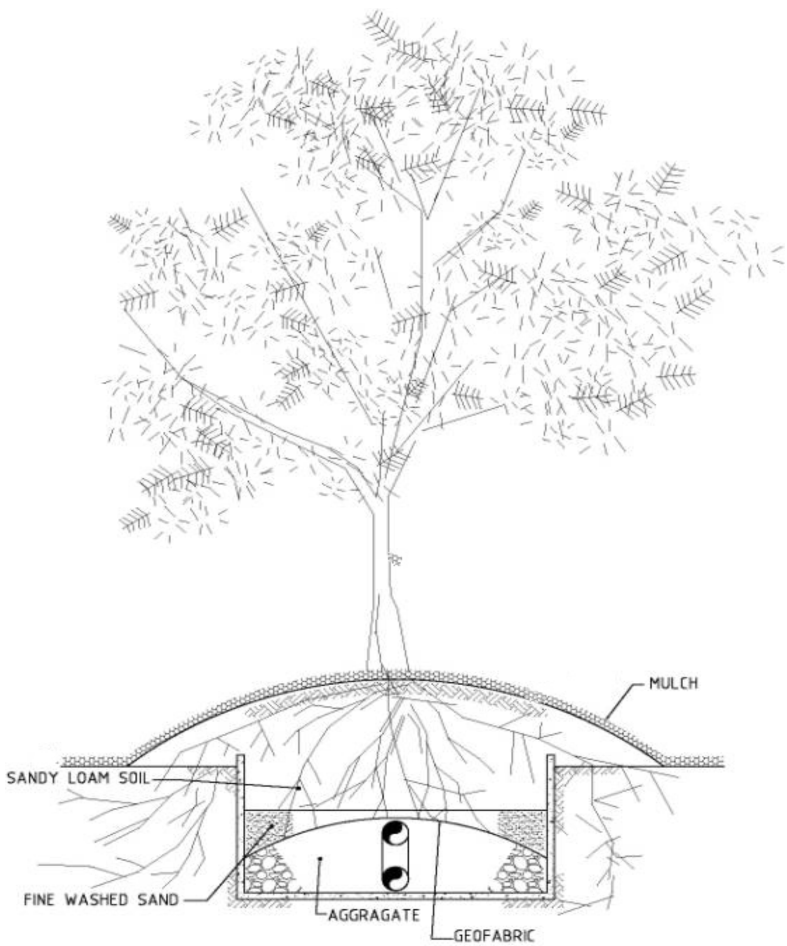
The Venturi valve number has been decreased as the new design requires one valve within the holding tank, whereas the old design required one at the start of each RET irrigation run. This reduces the maintenance requirements of the aeration system. This type of aeration system was installed at the St Lawrence Recreation Area and the Gem-Air Caravan Park site. It was retrofitted to the Rockhampton, St Lawrence Domestic and Yaamba trial sites. The remaining sites will be retrofitted as part of their maintenance cycle.

The effluent distribution system has been relocated so that it is after the Venturi valve at all sites. Thus if a malfunction occurs with the effluent distribution system it does not adversely affect the aeration system. All taps have been placed in lockable tap boxes to prevent non-authorised human interference. For future installations, instead of taps, it is planned that onsite wastewater distributing valves will be used to ensure equal volume delivery of effluent to RET irrigation runs. Members of the public cannot alter these types of valves and the polymer construction is non-corrosive and may have a longer life than standard metal taps.

6.3 Channel Design

The physical structure of the concrete channel was found to be durable and with no maintenance requirements. Clogging and maintenance problems were encountered with the various materials that filled the channels. These components of the system included the pipework, aggregate, terra-firma matting and/or geo fabric, and plastic lining. Methods have been found to alleviate these concerns or improve the performance of these materials. The new techniques have been incorporated into a new channel design shown in Figure 6.2.

Figure 6.2 Cross-section of new channel design



The major instance where clogging was found during the experiment occurred at the terra-firma matting or geo-fabric layer. As the plants matured a thick root mat formed just above the terra-firma matting. The thick root mat appeared to reduce the rate of effluent diffusion into the sandy-loam soil. To increase the rate of effluent transfer into the soil column and to minimise its degradation over-time the design of the channel has been changed.

The physical internal dimensions of the channel have been increased so that the volume is approximately 56% larger. This involved the channel having an increased width (+195 mm to total 995 mm) and depth (+175 mm to total 575 mm). This has meant that the new channel has a total volume of 1770 L, and an approximate effluent detention capacity of 590 L. Limiting factors to the increased size include ease of transport, including how many lengths a typical truck can carry, and the final weight of each length of channel (approximately 1 ton) and how that will affect handling during installation. By increasing the size of the channel the surface area between the terra-firma matting and the soil will increase and should enhance the transfer rate of effluent.

Additional measures aimed at increasing the effluent transfer rate into the soil can be seen in Figure 6.2. The aggregate layer is mounded to increase the surface area of the interface between geo-fabric and the upper parts of the channel. A coarse sand layer has been placed directly over the geo-fabric/terra-firma matting. The coarse sand as a substrate is expected to have a higher effluent transfer rate than the sandy-loam soil, being less likely to clog the pores of the geo-fabric. These measures were used at the Gem-Air Caravan Park site and observations so far have shown that soil moisture in the upper parts of the channel is relatively high. As this site has not matured the root matt has not fully developed. Additional study is required to assess the full effectiveness of these aspects of the new channel design.

Further developments have been incorporated into the channel design involving the pipework, aggregate, terra-firma matting/ geo-fabric, and plastic lining.

6.3.1 Pipework

The original pipework through the channel was 50 mm PVC DWV (Kele *et al.* 2000). With the increased dimensions of the new channel it was decided to increase the size of the pipework to 100 mm PVC DWV. A larger pipe size further reduces the chance of a blockage. If a blockage does occur a 100 mm pipe makes it easier for the specialised plumbing equipment used in such instances to remove the obstruction. All the connections between the septic tanks and holding tanks use 100 mm PVC DWV. The inlets and outlets on the tanks are manufactured to use this pipe size. By consistently using the 100 mm PVC DWV pipe size throughout the system some supply stock problems in regards to system installation and maintenance can be avoided.

The larger pipe size allows for a larger surface area for the wastewater to escape the pipe and enter the channel through the slots. This reduces the chance of a hydraulic short-circuit and the likelihood of wastewater passing through the pipework without entering the aggregate layer of the channel (Somes *et al.* 1999). This ensures that the primary-treated effluent has received further treatment through biological and physical filtration methods even if it eventually were to return to the holding tank due to the fact that it was not used in any one pass in the evapotranspiration process.

6.3.2 Aggregate

No problems were observed with the 10 mm blue metal aggregate used during the trial. At no stage did the aggregate clog or produce any observed negative impacts on the outcome of the trial. The Gem-Air Caravan Park trial did however show through the data of the sand and zeolite filter how the treatment performance of the aggregate layer might be improved.

Different media types support distinct biofilms, specific cation exchange properties, and have diverse physical filtration mechanisms (Kele *et al.* 2003; Saunders and Whitehead 2003). These media types include sand, zeolite, scoria, fly ash granules, clinoptilolite, and blue metal (Geary *et al.* 2001; Jantrania *et al.* 1998; Sim and Chrysikopoulos 2000). The RET design allows for a variety of different media types to be used in the aggregate layer. It is expected from an examination of the literature that the use of different media types will improve the treatment performance of the aggregate layer (Saunders and Whitehead 2003). Further trials are planned to investigate whether this hypothesis is correct.

6.3.3 Terra-firma Matting/Geo-Fabric

The aim of the terra-firma matting/geo-fabric in the trial was to provide a physical barrier (see Figure 6.3) that prevented the soil from infiltrating and clogging the aggregate layer while allowing the transfer of effluent into the soil column.

Figure 6.3 Terra-firma matting/Geo-Fabric

No clogging of the aggregate layer with soil was encountered in the trial. The unimpeded transfer of effluent through the matting into the soil column did not occur. At the Rockhampton site soil was excavated from 3 channels. During these excavations it was observed that the effluent transfer rate through the matting increased when it was physically manipulated and the silt clogging the pores was disturbed. New geo-fabrics have been developed since this trial was started that are reported to be clogging resistant and give sustainable hydraulic transfer rates. Additional trials are required to determine the type of geo-fabric for the RET system that has the best performance. Some other wastewater treatment and reuse technologies no longer use terra-firma matting/geo-fabric due to the clogging issue (Soar and Tinholt 2003). The possibility of removing the geo-fabric layer could also be investigated in future trials.

6.3.4 Plastic Lining

The plastic lining was installed over the RET system channels to stop rainfall intrusion. Over the course of the trial it was observed that the canopy development of the plants effectively prevented rainfall from falling on the RET system channels. The plastic lining had four disadvantages, a negative impact on the evapotranspiration rate, an inhibition of leaf litter and the associated carbon from that entering the soil in the channels, a barrier for soil aeration, and a maintenance problem.

Plastic mulch or a plastic lining will reduce the total evapotranspiration by 5-15% depending on the density of the plants in the channel, due to insulation of the channel soil surface from the atmosphere, and the dimensions of the reduction will depend upon changes in the reflectance and the interactions in the canopy that the mulch causes (Allen *et al.* 1998). Reference materials and local calibration are needed to determine a final value for the dimension of the plastic layer on evapotranspiration (Allen *et al.* 1998). The soil analysis (see Tables 4.1-4.17) showed that carbon levels in the channels generally declined over time. The plastic lining over the channels stopped leaf litter and mulch from entering the soil. This meant that soil carbon replenishment through leaf litter was impeded. The plastic lining also provided a barrier that most likely slowed soil aeration. A maintenance problem occurred with the plastic lining when high winds removed the mulch cover. The black plastic that was used to cover the RET channels was not visually attractive. To overcome this it was covered by a mulch layer so that it was inconspicuous and to minimise ultra-violet induced degradation. A new vegetative mulch layer needed to be regularly applied approximately every six-months over the plastic lining.

If the plastic lining were not to be installed the evapotranspiration rate would be higher, in our dry environment, and more effluent reuse would be possible, however the lining would be more advantageous under climates with a heavier rainfall. Carbon is an essential nutrient and needed for other nutrient transformations, such as in the nitrogen cycle (Li *et al.* 1998; Moore and Matos 1999). Effluent contains carbon, but this is frequently at levels considered too low for effective nitrogen transformation (less than 1.9g C /g of N) and plant nutrition (Li *et al*. 1998; Xie *et al*. 2003). The avoidance of a plastic lining will enable the natural process of soil carbon replenishment through leaf litter and mulch to occur. Several experimental sites showed that when the original venturi aeration system failed the soil pH became acidic. This was most likely due to application of the anaerobic effluent and the impaired soil aeration because of the plastic lining. The absence of the plastic lining should improve the aeration rate and minimise the soil acidification. To ensure that the plastic was completely covered the vegetative mulch needed to be replenished approximately every six-months. This added a maintenance step to the operation of the RET system. The removal of the plastic lining would reduce this maintenance step.

The plastic lining was one part of a three-fold system to prevent rainfall intrusion. Such prevention is important because it stops the stormwater from being polluted with effluent and protects the RET system from direct flooding. The plastic lining proved to be the least effective component for the prevention of rainfall intrusion because of its associated problems and its redundancy in the dry environment of the current experiments due to the shedding of water through canopy development. The other two approaches to the prevention of stormwater intrusion, that is, the aboveground level lip of the concrete channel and the mounding, worked well. There was no visual evidence for the infiltration of stormwater runoff into the channel either through the mound and or the lip of the channel. This was measured at the Rockhampton site though a float system in the holding tank and the pump return tank. This site had only occasional wastewater production on the weekends. During and after some heavy rainfall events that occurred on the weekends the level of wastewater in the holding and pump return tanks was observed. If stormwater did infiltrate the channels and flood the system the water would flow to the pump return tank. This tank was exactly 1 m^2 in size and the float was constructed so that every 1 cm that it rose represented 10 L. At no stage during a wet weather event was a non-wastewater generated, that is a pumped effluent related, rise observed.

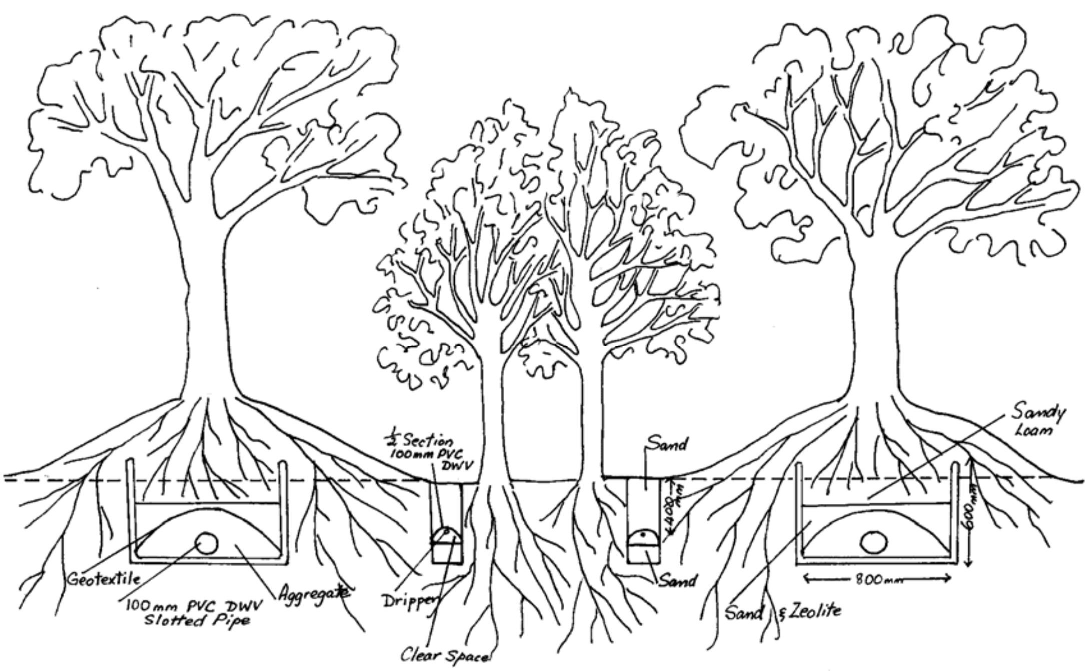
6.4 Emergency Overflow

Stormwater intrusion did occur at some sites through the emergency overflow soakage drain in high rainfall events. The emergency overflow was installed as an insurance against system failure due to extreme hydraulic surges and power/pump failure, and was designed so that the excess effluent had a safe underground disposal option until the problem was rectified or the surge had passed. Even with large buffers, such as a holding tank, hydraulic surges can adversely influence on-site treatment and reuse systems (Panswad and Komolmethee 1997). A treatment system designed for 10 EP cannot be expected to adequately treat wastewater when the design criteria are exceeded, such as at times when a large party occurs at the premises. Measures need to be included in the design to ensure that the wastewater treatment system still protects public and environmental health. The emergency overflow soakage drain was designed to do this task.

The emergency overflow soakage drains were never observed to fail due to hydraulic surges caused through human sources during the course of the trial. However in high rainfall events at the St Lawrence domestic site, Yaamba site and Rubyvale site stormwater runoff and overland flow were able to enter the emergency overflow soakage drain. The soakage drain then full of stormwater would backfill into the holding tank. This meant that the RET was overloaded and if the rain/overcast conditions prevailed the non-transpired effluent could exit through the emergency overflow soakage drain.

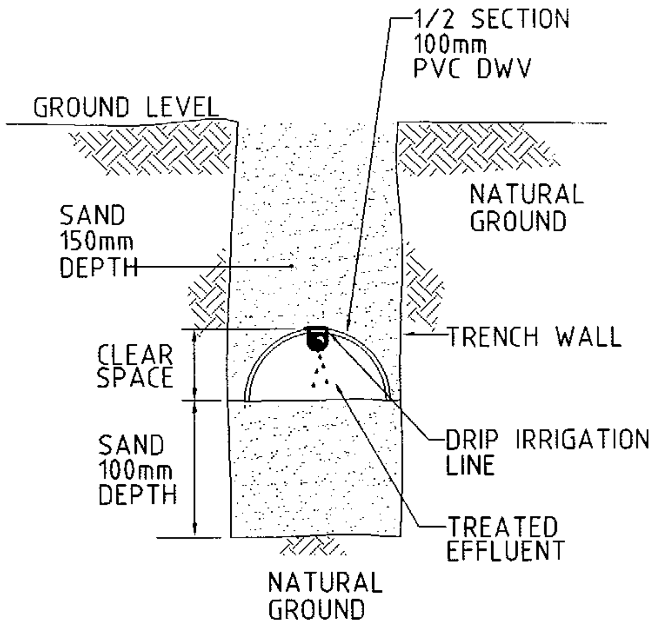
Physical interventions such as bunds to stop stormwater runoff from entering the soakage drain area were only partly effective. An alternative emergency overflow system trialled at the St Lawrence recreation area was sub-surface drip irrigation (see Figure 6.4). This system was chosen because there is no risk of a sub-surface drip becoming waterlogged with stormwater and backfilling the holding tank.

Figure 6.4 Cross-section of St Lawrence recreation sub-surface drip installation



The sub-surface drip irrigation system (see Figure 6.5) that was installed was the design recommended by the Centre for Environmental Training and that preferred by the NSW and Victorian EPA (CET 2001). This design is preferred because it minimises the likelihood of clogging, root intrusion, and surface pooling. The sand under the dripper encourages the dispersion of the effluent into the surrounding soil while also providing an extra form of filtration.

Figure 6.5 Cross section of sub-surface drip design



Additional design features of the sub-surface drip irrigation system include venturi aeration, intermittent dosing valves, and controlled rate drippers. Recent research at the Central Queensland University has shown that additional aeration of irrigation water supplied through sub-surface drip increases plant canopy size and transpiration, nutrient up-take, and tolerance to salinity (Bhattarai *et al.* 2004).

All effluent pumped through the sub-surface drip irrigation line was aerated by a venturi valve system. Intermittent dosing of effluent irrigation lines is considered best practice (Boller *et al.* 1993; Schudel and Boller 1990). The sub-surface irrigation line was split into separate irrigation runs. An intermittent dosing valve was used to ensure that the sub-surface irrigation runs are spelled from effluent irrigation. The use of controlled rate sub-surface drippers means that once a maximum irrigation application is decided the drippers physically cannot emit any more water. This eliminates the risk of over-irrigation along the sub-surface irrigation line. The design of this type of irrigation system makes it impossible for unsustainable irrigation rates to be reached. The intermittent dosing valve and controlled rate drippers means that, once determined, a maximum irrigation rate cannot be exceeded.

The sub-surface drip irrigation is run off a separate pump to that which irrigates the RET channel. This means that if the RET pump fails a safe effluent disposal method is still available until that pump can be repaired or replaced. An emergency overflow soakage drain still needs to be installed. As gravity based system it works even during power failures unlike pump based systems. However if a sub-surface drip irrigation system is installed the size of the emergency overflow soakage drain can be reduced. This has reduced the risk of stormwater runoff infiltration into the RET channel during high rainfall events. The holding tank and any additional sub-surface drip irrigation line pump tanks are all be fitted with high water alarms so that pump outs of excess effluent can occur if required.

Chapter 7: Conclusions

This study showed that a specific design of on-site wastewater treatment technology could be used in a diverse range of applications to meet the performance criteria set out in the relevant legislation. Over the course of the trial a number of design and infrastructure changes were incorporated as new systems were installed with the overall aim to improve system performance and sustainability. The infrastructure changes will, and in the more recently installed sites did, improve the physical construction of the sites resulting in reduced infrastructure failure. Additional research may be able to improve the infrastructure further.

The microorganism studies showed that potential pathogens existed in the effluent and within the RET channel soil column. However, colony forming counts were not at numbers that would cause concern for effluent irrigated 400 mm below the ground (WS/13/1 2000). The shutdown studies at the Rockhampton site showed that *E.coli* numbers could be reduced when no new inputs of effluent occurred but that *Salmonella* species increased. The Anakie site treated only greywater. The faecal pathogen study there showed that greywater does contain pathogens and that the microorganisms can survive in low concentrations within the irrigated soil. With the addition of other treatment technologies, such as that at the Gem-Air site Class A effluent could be produced and reused safely aboveground. In a similar vein, the assessment of the fruit grown at the Rockhampton site showed no elevated concentrations of potential pathogens.

The plant observations indicated that plants susceptible to natural occurrences of diseases, such as Papaw, should not be used within the RET channels. The choice to implement polyculture of species having different levels of biological activity appeared to be of benefit. Plant health overall was good.

The examinations of the original soil showed that commercially available soils quite often are not appropriate for the long-term application of effluent. The soil that had been amended with bagasse showed that soils may be sold by commercial operators that would not pass EPA guidelines in regards to effluent nutrient applications; specifically, in this case, in regards to phosphorus (ANZECC and ARMCANZ 1999). The original soil data showed that ideal soils were not used at the start of every trial site. Further research needs to be conducted into the soil blend used in the RET channels. It should be possible to create a soil blend with low concentrations of sodium and chloride and with high values for organic carbon % and CEC through the addition of organic matter (Graaff and Patterson 2001). Small clay amendments may be sufficient to immobilise phosphorus. This may produce a soil that is more sustainable for the long-term application of effluent.

The nutrient studies during the trial showed that no toxic accumulations of major, secondary or micronutrients occurred. Some plant nutrients, especially nitrate, were in limited supply. The secondary and micronutrients showed great variation between the sites. There was no consistency in regards to which nutrients would be in low concentrations and requiring a fertilizer application at any particular site. Nutrient concentration was not necessarily solely influenced by the chemical composition of the wastewater. As the plants could put roots into the soil external to the RET channels this could have had a major impact on which nutrients accumulated, remained stable, and decreased. For example, if the external soil had sufficient quantities of copper, it is possible that this is the reason that copper ions accumulated in the RET channel at a specific site. The research did show that wastewater irrigation does not provide all of the required plant nutrients in the quantities needed for healthy plant growth. Further research is required to determine what types of fertilizer are appropriate to add to effluent irrigation situations. It would not be correct to add a fertilizer that contained nutrients that were already in plentiful supply from the effluent.

Chlorinated hydrocarbons were not of concern during this trial. The chlorinated hydrocarbon study was limited and even the reticulated town-water had relatively low concentrations of chlorinated hydrocarbons when compared to the literature. An examination of a site where chlorinated hydrocarbons were present would be beneficial in understanding how the RET system would treat contaminants of this nature. Heavy metals did not accumulate to phytotoxic or unsustainable concentrations within the RET channels. It was evident that environmental pollutants such as cadmium, lead, and chromium did accumulate within the Sapphire RET channel soil, whereas they did not accumulate within the holding tank effluent at the site. The soil may have bound these heavy metals. The chemical toilet dump was not conducive to sustainable on-site wastewater treatment and effluent reuse.

The treatment chemicals used in the chemical toilets had notable adverse effects on the water quality, RET channel soil and the plants. Some of the soil in the RET channels in other locations actually improved in regards to CEC and ESP during the course of the trial. The soils that improved were irrigated with effluent that had relatively high concentrations of either calcium or magnesium ions. It may be possible to develop a solution that contains high concentrations of calcium and magnesium ions that could be added to the holding tank during scheduled maintenance inspections. This type of solution in a recirculating technology, such as RET system, may be able to increase the sustainable life of the channel soil. The RET system at Yaamba showed how important water type is in on-site wastewater treatment. This site had no chlorinated water in the wastewater; salinity did not increase markedly and, in most RET channels, neither did ESP. The calcium and magnesium ions in the groundwater helped to maintain a healthy CEC.

The Yaamba site was the first where the emergency overflow was flooded and back-filled the holding tank. This indicated that in extreme wet weather events involving large volumes of stormwater runoff the emergency soakage drain would not help dispose of excess non-transpired effluent. However, the stormwater infiltration did provide further evidence that salts could be leached out of the RET channel soil. The ability of the RET channel soil to be flushed of certain pollutants is important in determining the sustainability and viability of the system. Salts and sodium did accumulate within the RET systems. The Rockhampton site salinity leaching trial showed that salt concentrations within the RET system could be decreased. It also showed that a normal tank pump-out maintenance cycle could be adapted to facilitate the removal of salts from a RET system. The planned and unplanned salinity leaching trials showed that salts could be removed from the RET channel soil and the recirculated effluent within the holding tanks.

Several areas for further study were identified within the trial:

1. Techniques to improve the soil blend placed within the RET channels so that the number of years that it can treat effluent in a sustainable manner can be extended.
    a. Addition of organic carbon and placement of organic carbon within the RET channel layers.
    b. Addition of new types of filter media to the RET channel soil blend; such as scoria, charcoal and zeolite, to provide additional treatment.
2. Investigations into pathogen movement through the RET channel soil.
3. Solid movement through the internal RET channel pipework.
    a. How do solids exit each RET channel, as they must rise to the discharge point?
    b. What velocity is required for this to occur; is the maintenance air-discharge sufficient to obtain this velocity?
4. Treatment performance of redesigned physical infrastructure of the system.

a. How does the new technologies improve overall treatment performance?

5. Revised plant selection.

   a. Select plants more resistant to disease and herbivory.

   b. Select plants to remove particular chemical elements of concern through advanced phytoremediation techniques.

6. Additional research sites that produce different types of wastewater.

   a. Specific site characteristics had a large impact on the various systems in the trial. Greater understanding on how the RET system will work with different wastewater qualities is required.

The trials confirmed that the RET system can be a viable form of on-site wastewater treatment and reuse technology. Further research should be undertaken to improve the treatment performance of the system and increase the sustainable life of its treatment components.

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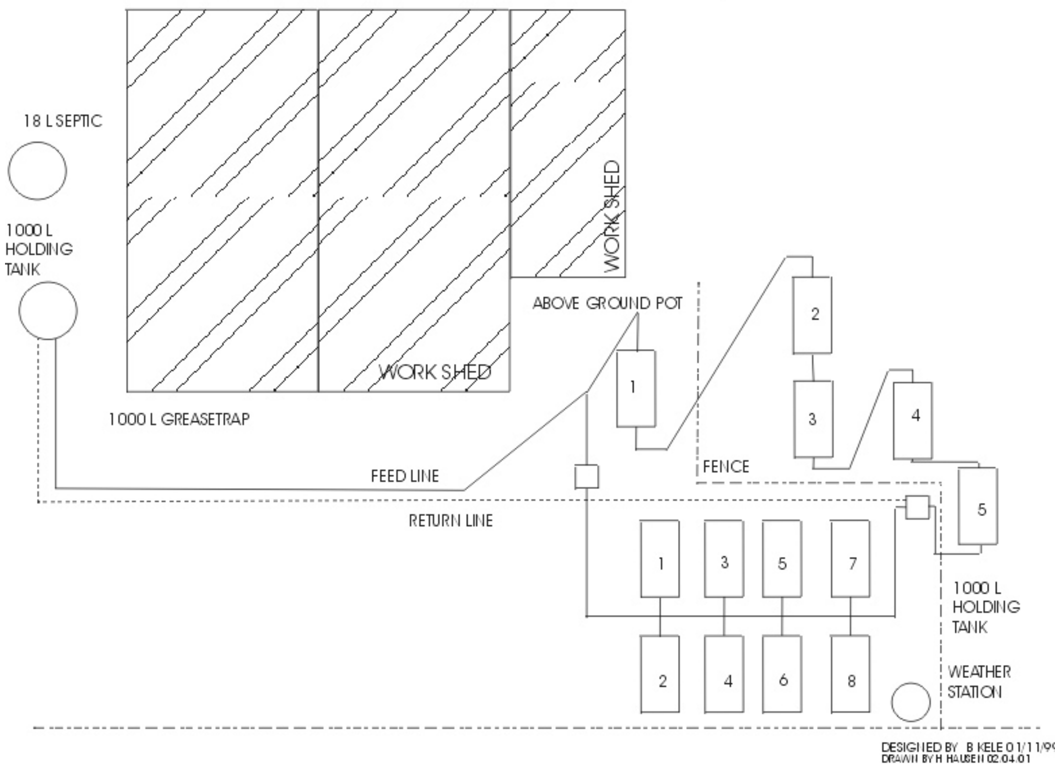
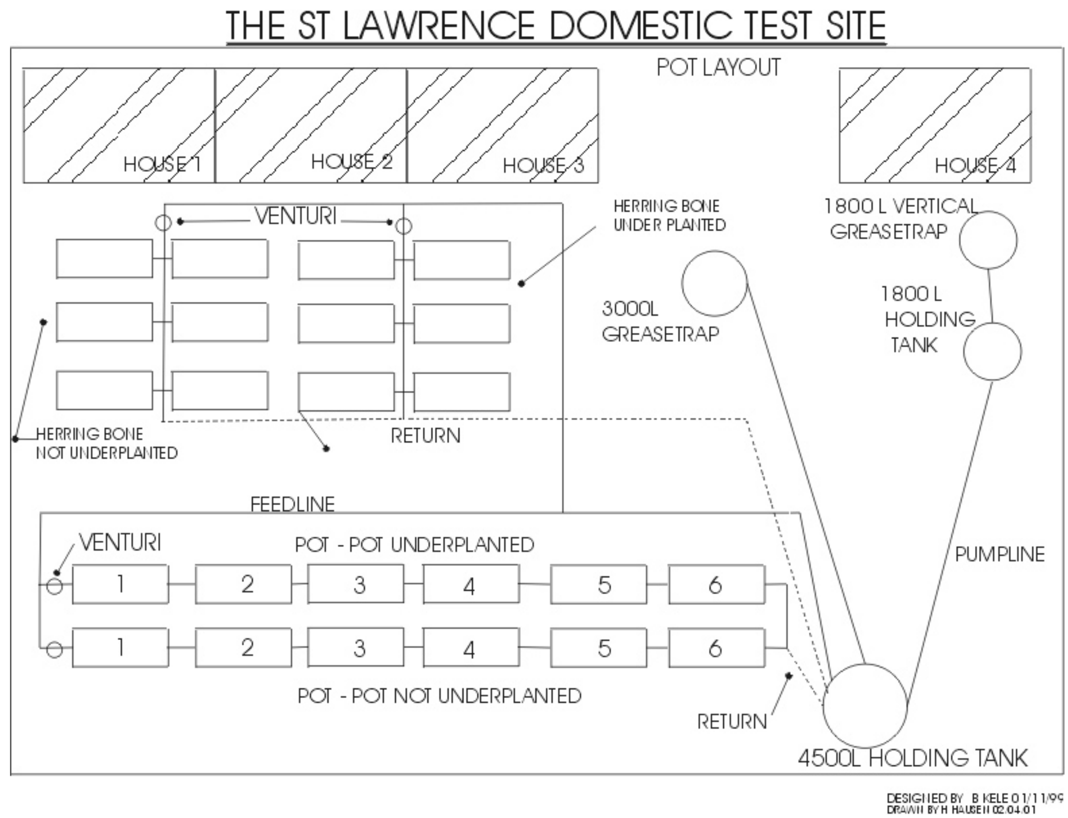
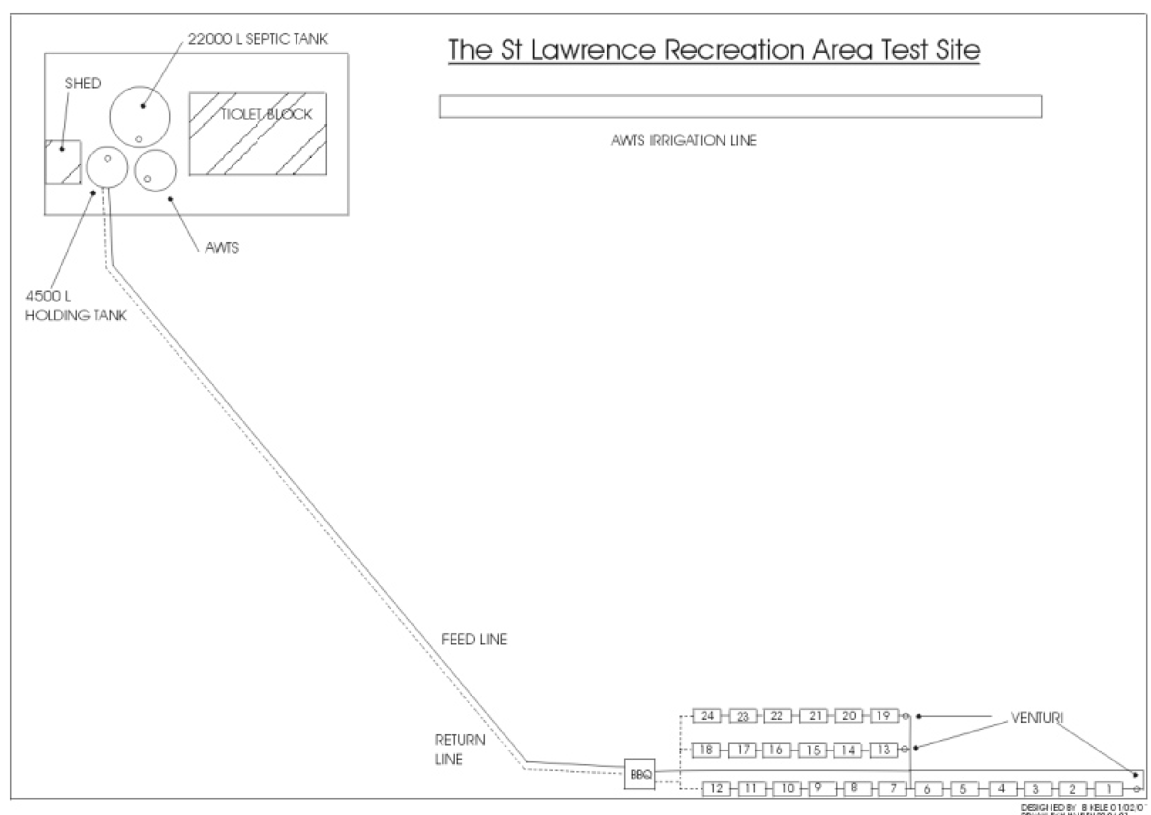
THE ROCKHAMPTON TEST SITE




THE ST LAWRENCE DOMESTIC TEST SITE
POT LAYOUT
HOUSE 1
HOUSE 2
HOUSE 3
HOUSE 4
VENTURI
HERRING BONE
UNDER PLANTED
1800 L VERTICAL
GREASETRAP
3000L
GREASETRAP
1800 L
HOLDING
TANK
HERRING BONE
NOT UNDERPLANTED
RETURN
FEEDLINE
VENTURI
POT - POT UNDERPLANTED
PUMPLINE
1
2
3
4
5
6
POT - POT NOT UNDERPLANTED
RETURN
4500L HOLDING TANK
DESIGNED BY B KELE 01/11/99
DRAWN BY H HAUSEN 02.04.01


22000 L SEPTIC TANK
The St Lawrence Recreation Area Test Site
SHED
TIOLET BLOCK
AWTS IRRIGATION LINE
AWTS
4500 L
HOLDING TANK
FEED LINE
RETURN
LINE
BBQ
VENTURI
24 23 22 21 20 19
18 17 16 15 14 13
12 11 10 9 8 7 6 5 4 3 2 1
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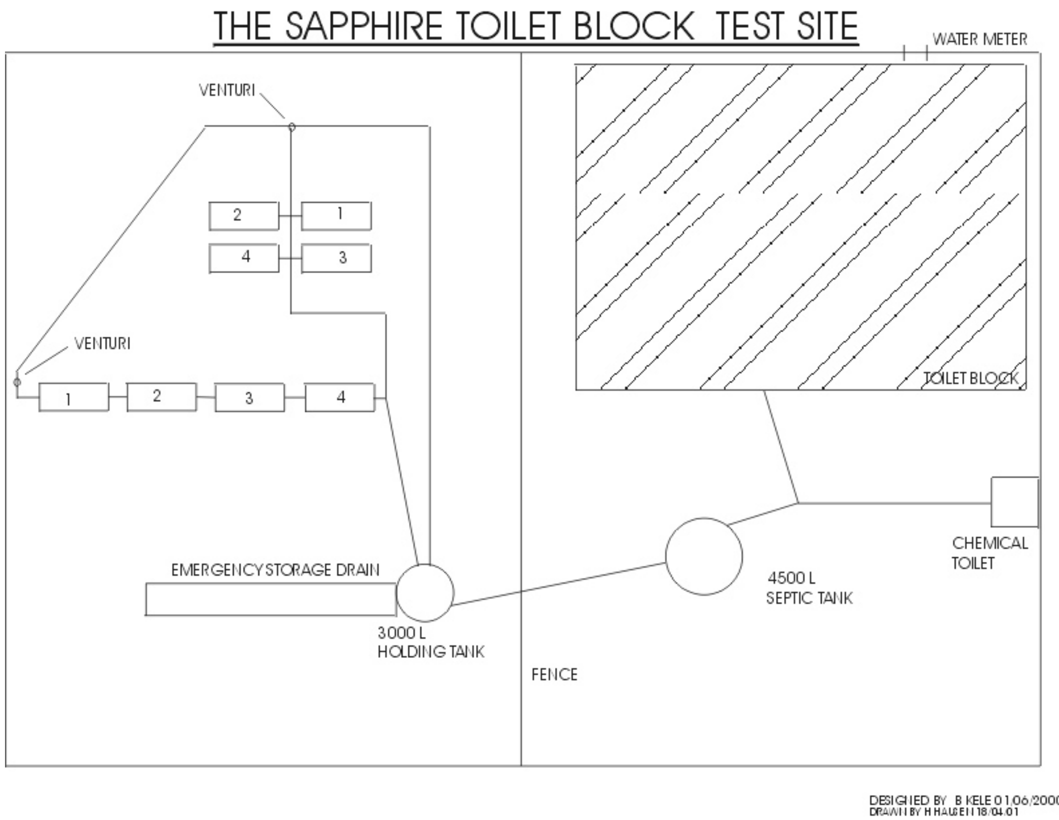
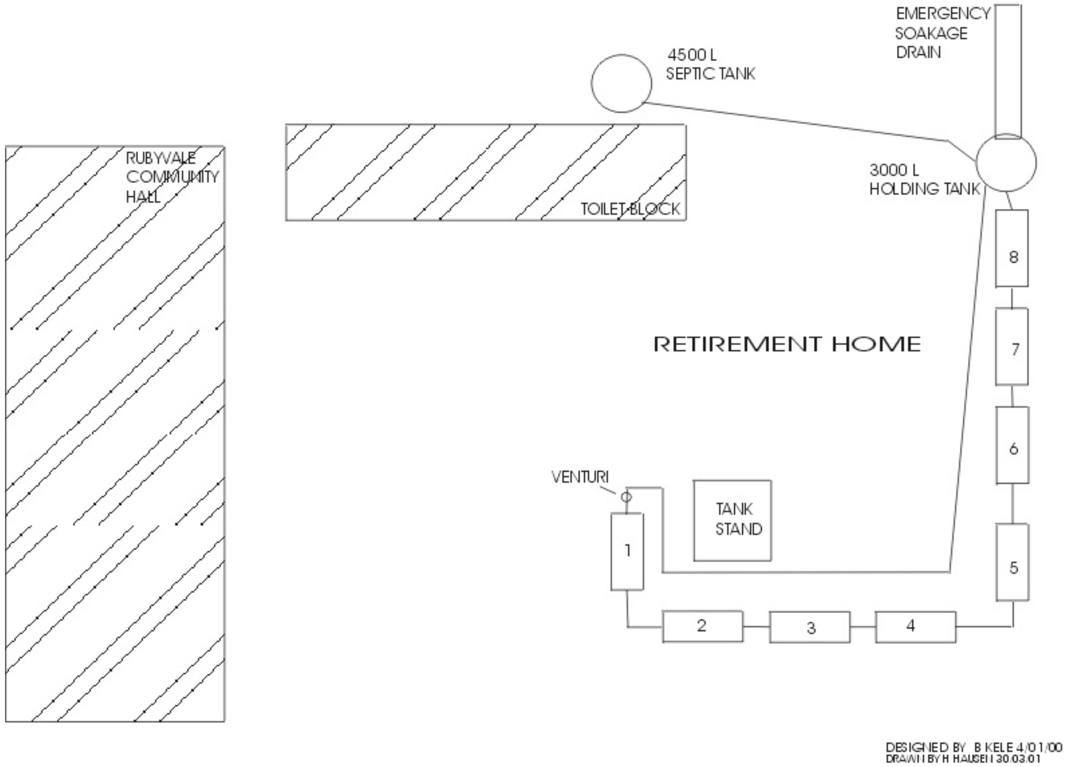

THE SAPPHIRE TOILET BLOCK TEST SITE
WATER METER
VENTURI
2
1
4
3
VENTURI
1
2
3
4
TOILET BLOCK
CHEMICAL
TOILET
EMERGENCY STORAGE DRAIN
4500 L
SEPTIC TANK
3000 L
HOLDING TANK
FENCE
DESIGNED BY B KELE 01/06/2000
DRAWN BY H HAUSEN 18/04/01

THE RUBYVALE COMMUNITY HALL TEST SITE



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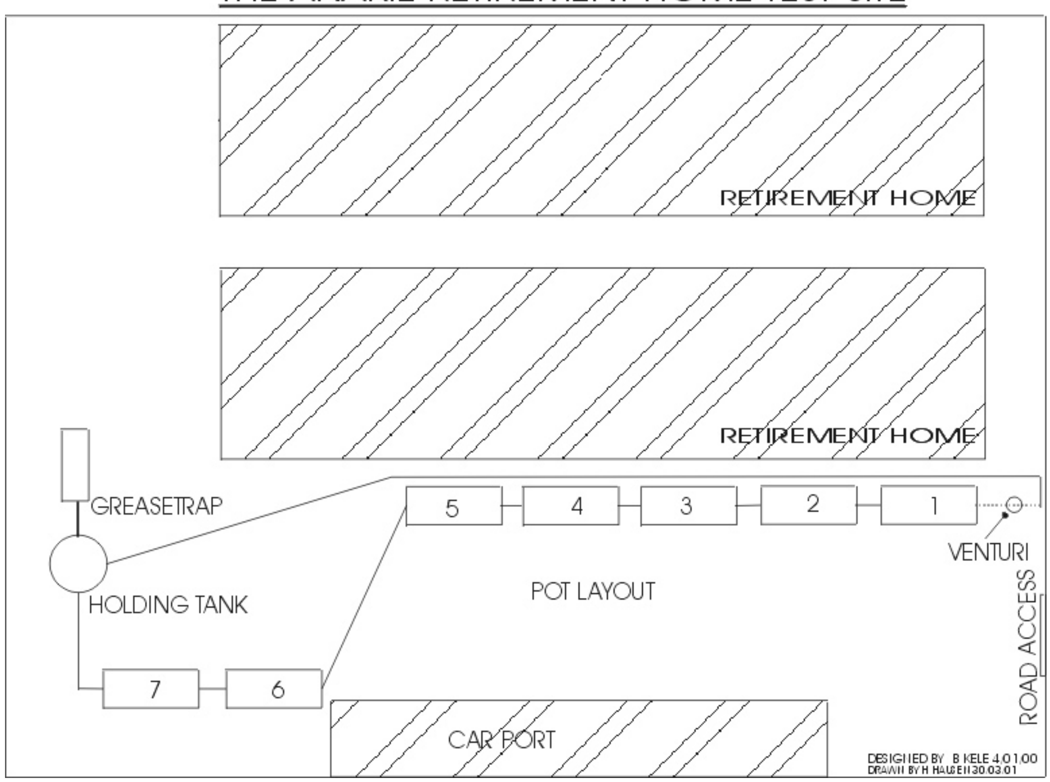

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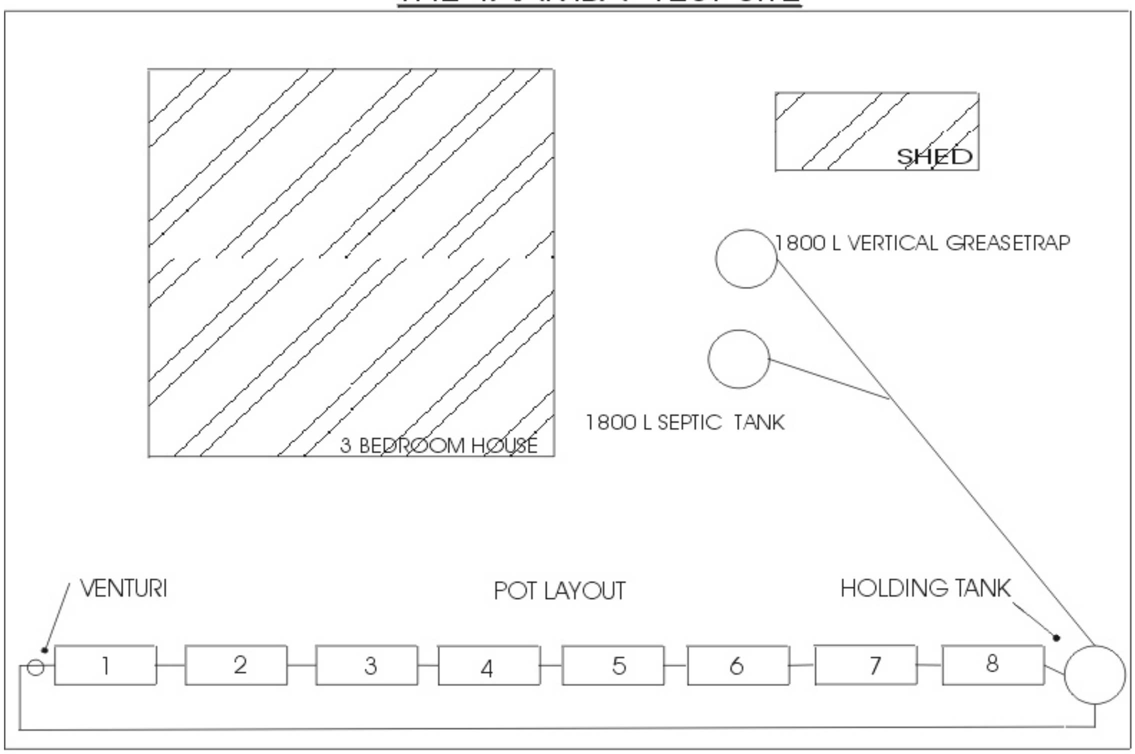

DESIGNED BY B KELE 4/01/00
DRAWN BY H HAUSEN 02/04/01